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ABSTRACT

This volume reports on the initial phase of a technology assessment of personal computers. First, technological developments that will influence the rate of diffusion of personal computer technology among the general populace are examined. Then the probable market for personal computers is estimated and analyzed on a functional basis, segregating it into four submarkets: the home, education, small business, and large organizations. Next, some possible evolutionary forms of the personal computer are briefly described along with an alternative mode of development of personal computing. In conducting this phase of the assessment, the researchers utilized a survey of existing personal computer users and market growth models for large ticket consumer durable goods to predict the probable growth and maturation patterns of the personal computer market. Tables of data are included as well as an extensive bibliography. (Author/LLS)

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A TECHNOLOGY ASSESSMENT
OF
PERSONAL COMPUTERS:
VOLUME II
PERSONAL COMPUTER TECHNOLOGY,
USERS, AND USES

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Any opinions, findings, conclusions and/or recommendations expressed herein are those of the authors and do not necessarily reflect the views of the National Science Foundation or of the University of Southern California.

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Preface

This set of reports is the last in a series covering the first two years of progress of the Personal Computer Assessment Project at the University of Southern California. The Principal Investigator of the project is Jack M. Nilles, Director, Interdisciplinary Programs. Organizationally, the Office of Interdisciplinary Programs is a unit of the Office of the Executive Vice President of USC. A technology assessment is a complex, broad-scope activity. As such, it requires the participation of researchers from a number of disciplines and the cooperation of a variety of experts from outside the university. The purpose of the Office of Interdisciplinary Programs is to develop such projects on a university-wide basis.

The USC research team has included the following individuals:

Jack M. Nilles	Director, Interdisciplinary Programs Office of the Executive Vice President (Project Director; Impact and Policy Analysis; Reports Editor)
F. Roy Carlson, Jr.	Assistant Dean, School of Engineering Director, Engineering Computer Lab (Technology Forecast; Scenario Development; Education Policy Analysis)
Herb Dordick	Director, Center for Telecommunications Policy Research Annenberg School of Communications (Telecommunications Policy)
Paul Gray	Professor, Decision Sciences [Now Chairman, Management Science and Computers, Cox School of Business, Southern Methodist University] (Scenario Development; Impact Analyses)
John P. Hayes	Associate Professor, Electrical Engineering (Technology Forecast)
Milton G. Holmen	Professor, Management, Public Administration (Market Analysis)
Michael J. White	Associate Professor, Public Administration (Policy Methodology; Employment Policy)
Celeste B. Akkad	Office of Interdisciplinary Programs Project Assistant (until June, 1980)
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Research Assistants

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Sean Casey (Scenario Development)
Terri Gray (User Surveys)
Patricia Walters (Scenario Development, Education)

In addition to the project staff, we have been given much valuable assistance and advice from a Board of Advisors. The composition of the Board has been as follows:

Robert W. Barmeier	Director, Planning Research Sears, Roebuck Company
Alfred Bork	Professor, Department of Physics University of California, Irvine
John Craig	Publisher, InfoWorld
Robert Daly	Special Assistant to the Director Office of Technology Assessment, U.S. Congress
Edward E. Faber	President, Computerland Corporation
Portia Isaacson	Research Fellow, Electronic Data Systems
Hank Koehn	Vice President, Futures Research Security Pacific National Bank
Ryal R. Poppa	President, PERTEC Computer Corp.
John Ratliff	Consultant
R. B. Shirey	Vice President, General Telephone Company

We have also been fortunate to enlist the cooperation of a number of experts in various aspects of our research by means of our Delphi surveys. The Delphi panelists and our advisors contributed their time, interest and insights far beyond the call of duty. We are grateful for the time spent by those who participated in the surveys associated with the project.

Finally, we are greatly indebted to Dr. G. Patrick Johnson, of the National Science Foundation, for his interest, timely advice, and encouragement. Although many improvements in our research have resulted from the contributions of these advisors, panelists, and respondents, any failings must remain the responsibility of the research team. Readers interested in gaining further information may contact:

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CONTENTS

PART I. INTRODUCTION AND SUMMARY 1-1

PART II. TECHNOLOGY: State of the Art Report and Forecast 2-1
1. Introduction 2-1
1.1 Objective 2-1
1.2 A Brief History of Computer Technology 2-1
1.3 Personal Computer Technology 2-5
1.4 Forecasting Methods 2-8
2. Integrated Circuits 2-9
2.1 Physical Characteristics 2-9
2.2 Microprocessors 2-12
2.3 Memories 2-14
2.4 Special Purpose Processors 2-14
3. Peripheral Devices 2-15
3.1 Secondary Storage 2-16
3.2 Standard Input/Output Devices 2-20
3.3 Nonstandard Input/Output Devices 2-22
4. Software 2-25
4.1 Introduction 2-25
4.2 Programming Language 2-26
4.3 Systems Programs 2-28
5. Standards 2-29
5.2 Personal Computer Standards 2-30
6. Networks 2-31

PART III. PERSONAL COMPUTER USERS AND USES 3-1
2. Personal Computer Questionnaire 3-1
2.1 Personal Computer Owners 3-1
2.2 Uses 3-4
2.3 Languages 3-4
2.4 CPU Memories 3-4
2.5 Network Access 3-5
2.7 Other Electronics Owned 3-6
2.8 Investment in Personal Computer Equipment 3-6
2.9 Organizational Memberships 3-8
2.10 Other Computer Usage 3-8
2.11 Sources of Funding for Personal Computers 3-8
2.12 Relationships with Personal Computing Investment 3-10
3. Survey Analysis 3-16
4. Modeling Markets for Technological Products 3-17
4.1 Introduction 3-17
4.1.1 Underlying Assumptions: The Bass Model 3-24
4.1.2 An Example: Electronic Calculators 3-24
4.2 The Autocatalytic Model 3-24
4.3 A Simple Repurchase Model 3-33
5. Estimating the Future Personal Computer Market 3-35
5.1 Estimates from Other Sources 3-35
5.2 Development of Total Market Estimates 3-35
5.2.1 Fitting to Data 3-35
5.2.2 Future Market Components 3-35
5.2.3 Estimate Methodology 3-41
5.2.4 Nominal Estimates 3-43

PART IV. SOME THOUGHTS ON POTENTIAL SYSTEM CONFIGURATIONS AND ALTERNATIVES 4-1

1. Network Information Services: Telecommunications Based Alternatives 4-1
1.1 Commercial Computer Time Sharing 4-1
1.2 Teletext and Videotex Services 4-2
1.3 Datacast 4-3
1.4 Acceptance of Network Information Services 4-3
1.5 Forecast 4-4

PART V. BIBLIOGRAPHY 5-1

APPENDIX A-1

PART I

INTRODUCTION AND SUMMARY

This volume is a revision and update of the first working report of the Personal Computer Assessment Project at the University of Southern California. The purpose of the project, which was partially supported by the National Science Foundation under grant number PRA78-05647, was to assess personal computer technology, its potential applications, the probable societal impacts, and the public policy issues related to the most significant of these impacts. From the point of view of the research team, the ultimate goal of the project is to examine and illuminate the public policy issues related to this rapidly developing new technology.

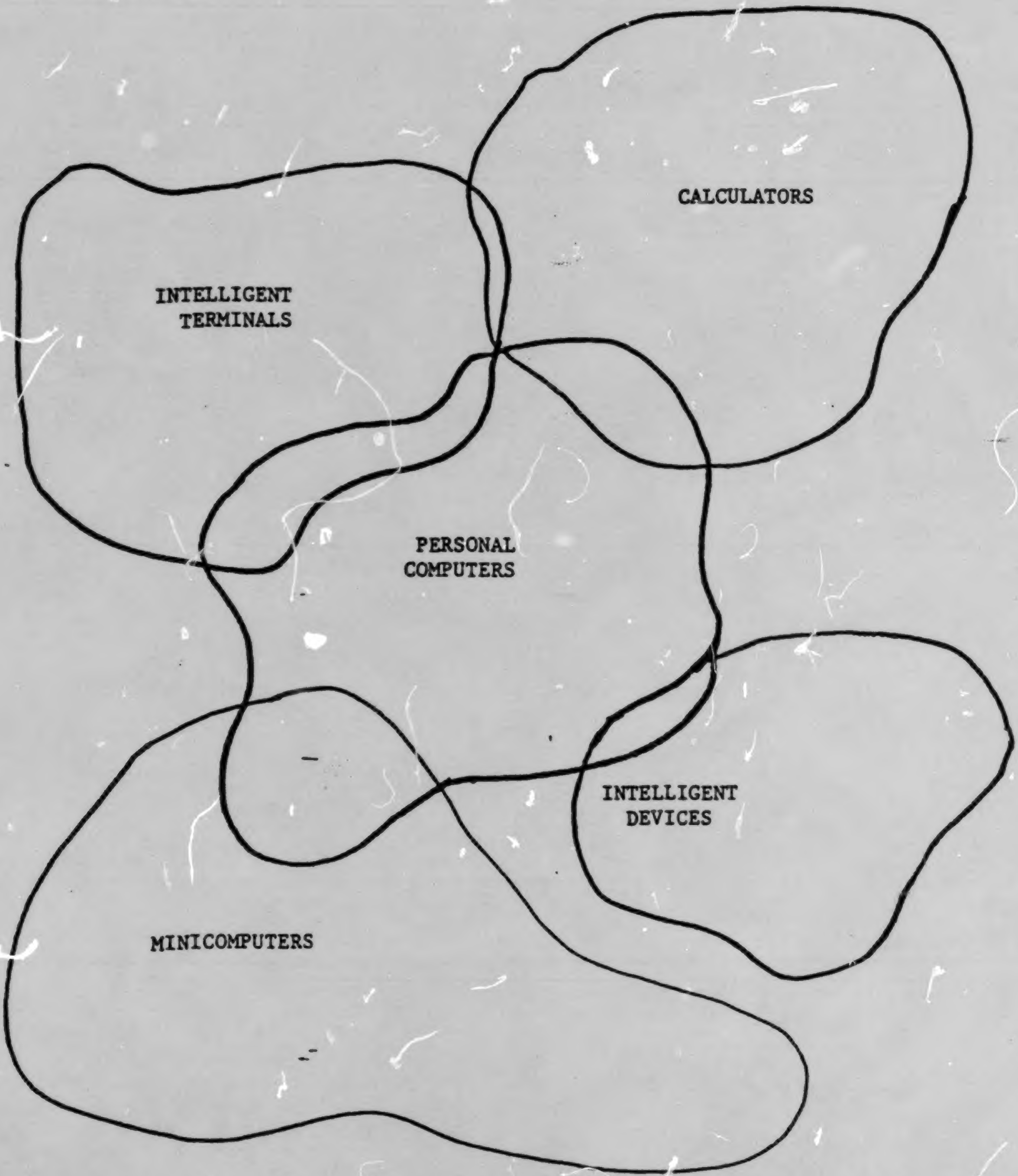
The Personal Computer Assessment Project was divided into three sequential phases: 1) market and technology survey and "baseline" forecast; 2) impact analysis and 3) policy analysis. During the first phase, which is the topic of this volume, emphasis was placed on developing forecasts of the potential population of users of personal computers, the general uses to which they will put these systems, and the underlying technology which will support or prohibit various desired uses. These factors are all interrelated: unless there is a fundamental technological capability, certain uses cannot be made of personal computers; unless some minimum level of demand develops (at least for certain capabilities) at certain prices, the technology will not be developed for this market; demand for a technological capability is in part dependent on the perception by the potential users of the technology that such capability exists or is at least practical.

It is important to begin a technology assessment with a study such as the one reported here, because ultimately the public policy issues arising from the use of technology are related to the extent to which the technology is used and the ways in which it is used. Thus, for example, if there were only 100,000 automobiles in the United States, with little prospect that the automobile population would grow beyond that number, the arguments for performing a technology assessment of automobiles might not be particularly persuasive. Similarly, if it could be shown that it is not likely that there will be more than 100,000 personal computers in the United States, and that the impact of the use of an individual personal computer would be relatively insignificant, there would be little sense in pursuing an assessment of personal computer technology. The information we have gathered to date leads us to conclude that by 1990 there could be more than 40 million personal computers in use and that the implications of the various uses to which they will be put may be substantial. Consequently, it is important to obtain an idea of the magnitude of the rates of growth and diffusion of personal computer technology and of the types and importance of the uses to which the technology may be put. These topics are dealt with in some detail throughout the remainder of this volume.

Definition. The term "personal computer" is not a particularly satisfactory one for the object of our research. Its greatest virtue is that it is the most succinct term which still emphasizes one of the primary characteristics of the technology with which we are concerned: the existence of a stand-alone, general purpose information processing capability which is affordable by an individual. However, our study is not confined to computers that are solely owned by individuals, or to computers which are only used in the home, for that matter. Figure 1-1 (which symbolizes interrelationships between "personal" and other types of computing machines), together with the definition provided below, gives a somewhat better idea of the concerns of

FIGURE 1

The Universe of Small Computing Machines


CALCULATORS
INTELLIGENT TERMINALS
PERSONAL COMPUTERS
INTELLIGENT DEVICES
MINICOMPUTERS

this research.

> A **personal computer** (PC) is an essentially stand-alone, general purpose computer system, containing one or more microprocessors, which is purchased and/or operated by an individual or small (say, 2 to 5) group of individuals. It requires interaction at a conversational level between it and its operators at least part of the time it is functioning (i.e., it is not used solely for process control or similar, non-interactive utility functions). Its cost is such that the individual owner can justify its purchase on the basis of personally received benefits, financial or otherwise. The individual owner need not be a computer professional nor need the computer be used solely for recreational, eduational or business purposes.

Clearly, there may still be a little ambiguity in this delineation of the problem area, but the key words that have guided our research thus far are "affordable" (that is, a personal computer is not a contemporary minicomputer but something which, together with a reasonable array of applications software, costs anywhere from $500 to $15,000; and "general purpose" (which separates it from intelligent devices and from personal computing using a larger machine).

Strategy. Even with these "borders" on our definition there is some overlap with related uses of computer technologies. This overlap, together with difficulties in obtaining accurate, hard data about the existing market for, and uses of, personal computers, lends a certain aura of imprecision to the estimates presented. This gave the physical scientists and engineers in our research group feelings of great uneasiness at times and caused us to adopt a strategy of concentrating on the identification of the key public policy related events and trends in the development of personal computer technology rather than on the detailed numbers. This strategy is a little like earthquake or weather prediction at its present stage of development. We hoped to be able to forecast that a certain kind of event would occur in the future and that it would most likely occur during a certain, relatively short, time period. The actual occurrence of these events (such as an earthquake, a sunny day or development of low-cost educational software) actually depends on a great many other factors, many of which we may not explicitly recognize or be able to measure at present. Therefore, our approach was to spend less time in trying to predict the dates of the occurrences than in estimating the effects of the occurrence of the event in question.

Thus, we **are not** attempting to forecast THE FUTURE as if only one possible future exists. To do so would be both naive and foolhardy at our present state of knowledge. What we have been trying to do is estimate the most probable combinations of future events, their sequences, and their interrelationships so that we may be better prepared to deal with the actual future when it becomes the present. If we can give the policy-maker a better idea of the most probable issues which may develop in the future and of the consequences of alternative policies chosen to deal with them, our purpose will have been served.

Summary. The remainder of this volume is divided into four parts. In the first of these (Part II), we examine the technological developments that will influence the rate of diffusion of personal computer technology among the general populace. Unlike some technological trends, such as the development of nuclear fusion energy on a commercial basis, there is little uncertainty concerning the future practicability of personal computer technology. No major technological break throughs are necessary at this stage before a fairly substantial market can be developed, although some innovations, such as very low-cost mass memories and software, may have substantial market (and policy) effects.

The next part of the volume, complementary to the technology forecast, is an estimate of the probable market for personal computers as a function of time. This task is much more difficult to deal with explicitly because, while personal computer technology is a logical extension and branch of the technology used in large computers, many of the future consumers of personal computer technology are likely to have very little resemblance to the present consumers of mini- and macrocomputer technologies, namely medium to large size organizations. Furthermore, the personal computer as such did not exist, except in kit form, prior to 1975. Contemporary manufacturers of personal computers and associated hardware and software are, with few exceptions, small to medium size companies. Few of these are willing to divulge current market information such as sales volume in either number of units or dollars. Early descriptions of personal computer applications in the popular literature tended to be of the "gee whiz" variety, although as the field has "matured" (if one can consider a five year old industry to have reached any stage of maturity) more attention is being paid to the practical aspects of computer applications. Mass marketing of personal computers, as would be evidenced, for example, by their distribution through major national general retailers, has just begun. In short, there is considerably more uncertainty about the probable course of events of the personal computer market than there is about its underlying technology, most of which does not depend on the personal computer market for its development.

The market forecasting picture is not entirely bleak however. We do have two useful tools to help us formulate our forecast. One of these is a survey that the research team made of existing personal computer users. This survey clearly involved an atypical set of respondents in that existing users tended at that time to be from the educated, upper middle class, while potential users of personal computers must come from a broader set of economic groups of the market is to grow. Nevertheless, to the extent to which we can compensate for this present bias we can expect to construct a reasonable forecast of demand, growth and elasticity. Secondly, we can make use of well-established, existing market growth models for "large ticket" consumer durable goods as a means for predicting the probable growth and maturation patterns of the personal computer market. Both of these tools are discussed in Part III.

We have analyzed the future market on a functional basis, segregating it into four submarkets. These are: the home, education, small business and large organizations, each with its own objectives and behavioral characteristics. [In Volume III these are further compressed into the consumer, education and office markets.] Our analyses lead us to believe that the market will build at an accelerating pace, reaching a peak rate of "new" buyers coming into the market in the late 1980s and reaching the peak number of new buyers in the early 1990s. Thus, the policy issues which are dependent on the number of units in use will start to become significant in the mid '80s, although some issues (computer crime and privacy issues, for example) may start to appear earlier. Estimating the PC applications and impacts leading up to these issues have been the main tasks of the past year of our research.

Part IV contains a brief description of some possible evolutionary forms of the personal computer and of an alternative mode of development of personal computing. Part V is a bibliography of works referenced in this volume.

Note: this volume specifically does not discuss the policy issues andsocietal implications related to the personal computer. These issues are discussed in Volume 3. For an overall description of the strategy for this project, see "A Technology Assessment of Personal Computers," by Jack M. Nilles, et.al., OIP/PCTA 78-1.

PART II

TECHNOLOGY: STATE OF THE ART REPORT AND FORECAST

1. INTRODUCTION

1.1 Objective

The purpose of this portion of the USC study is to forecast the technologies, both hardware and software, likely to be used in personal computers through the decade of the 1980's. A nominal ten-year forecast period has been chosen because it typically requires about ten years for an invention based on newly-discovered physical phenomena to be developed into a marketable product. Thus, most of the commercial products appearing by 1988 are likely to be based on physical principles known today. The very rapid rate of progress in computer technology makes longer range forecasting extremely difficult and speculative.

1.2 A Brief History of Computer Technology

The evolution of digital computers has been mainly influenced by improvements in hardware technology (Hayes, 1978). Particularly significant in this regard are the basic computing elements (switches or gates) and memory elements employed.

The earliest attempts to build a general purpose digital computer were made by the Englishman Charles Babbage (1792-1871) in the 1830's (Morrison and Morrison, 1961). Babbage designed a computer, the Analytical Engine, which embodied all the essential features of a modern programmable digital computer. He proposed to build it using mechanical technology with gears, levers, etc. forming the computing elements, and counter wheels forming the main memory. Interestingly, he also intended to use punched cards, a technology that is still widely used, for program and data storage. Only a small part of Babbage's Analytical Engine was built; the technological problems of building a mechanical computer of its complexity proved to be insurmountable.

Workable general purpose computers were first completed in the early 1940's using electromechanical computing elements (relays). The Harvard Mark I computer constructed by IBM under the direction of Howard Aiken (1900-1973) became operational in 1944. Less widely known is the relay computer, the Z3, built by Konrad Zuse in Germany in 1941. Relays were almost immediately replaced as the basic switching devices by vacuum tubes which are much faster. (The triode vacuum tube had been invented around 1906.) The resulting electronic computers are now referred to as "first generation" computers. Vacuum tube computers proliferated very rapidly in the late 1940's. The first commercial computer was the UNIVAC 1, which was delivered in 1951. Table 2-1 summarizes these and other electronic computer events.

The second computer generation (1955-1965 approximately) saw the replacement of vacuum tubes by transistors. The transistor, a semiconductor device invented at Bell Telephone Laboratories around 1948, is much smaller and consumes far less power than a vacuum tube. It remains, in many variations, the basic switching element of all current computers. A significant advance occurred with the invention in 1959 of integrated circuits, which allow complex circuits containing transistors, resistors and other electronic components to be manufactured in a single semiconductor (silicon) chip (Wolff, 1976). Integrated circuit (IC) technology development has proceeded at an extraordinarily rapid rate. The main goal of this development has been to increase the number of basic elements contained in one

TABLE 2-1

A BRIEF HISTORY OF ELECTRONIC COMPUTERS

			REF
--	First ever electronic (Atanasoff-Berry) computer	1940-42	(1)
--	Z3 relay computer	1941	
--	Mark I Sequence-Controlled Calculator, Manhattan Project (51x8x6 ft.), 5 tons	1939-44	(1)
--	ENIAC, 18K vacuum tubes, hardwired, 3K ft^3 140 KW, 90 tons, 100 kHz clock, 1K RAM, 16 K RAM	1945	(1),(2)
--	First junction transistor, Bell Telephone Laboratories	1948	
--	EDSAC, first stored program computer	1949	(1)
--	Sixty computers built, no two alike	1946-1950	(1)
--	UNIVAC I, first assembly line version(45 built)	1950	(1)
--	First "grown" transistor produced (Bell Labs)	1951	(2)
--	First integrated circuit	1959	
--	MOS transistor invented	1960	(2)
--	"Moore's Law"(Complexity of a chip will double yearly for ten years)	1965	(2)
--	15 K computers in operation	1966	(1)
--	80 K computers in operation (in U.S.?)	1970	(1)
--	106K computers in existence	1970	(3)
--	First computer-on-a-chip (MSI)	1970	(2)
--	130 computers in existence (85K in U.S.)	1971	(4)
--	First personal computer kit (MITS ALTAIR)	1974	
--	Moore's Law, Stage II (Complexity will double every two years for 10 years)	1975	(2)
--	Intel 8086 -- 29K transistors on a 0.05 in.^{2} chip (570K/in.^{2})	1978	
--	250,000 personal computers in existence	1978	(5)
--	1 million personal computers in existence	1980	(5)
--	Annual sales of 1 million personal computers	1982	(5)
--	10M components on a chip (rough equivalent of Cray-1)	1985	(2)

(1) Social Effects of Computer Use and Misuse. J. Mack Adams and Douglas H. Haden. New York: John Wiley and Sons, 1976. pp.43ff.

(2) "Reflections in the Past and Thoughts about the Future of Semiconductor Technology." C. Lester Hogan. Interface Age. March, 1977. pp.24ff

(3) World Facts and Trends. John McHale, Collier Books. 1972. p. 56. Ref. "Computers in Eastern Europe," Ivan Bereny, Scientific American, October, 1970. p.104.

(4) The Conquest of Will. Abbe Moshowitz. Addison Wesley. 1976. p. 54.

(5) USC research team estimates.

IC. This in turn reduces the number of distinct components (IC's) and, therefore, the cost of a complete system. Because the manufacture of IC's is almost entirely automated, the cost of IC's produced in large quantities is very low. Furthermore, this cost is relatively independent of circuit complexity. Thus, IC's have resulted in a substantial decrease in the size and cost of computers. The rate of IC technology development was fairly accurately predicted in 1965 as causing a doubling in the number of components per IC every year (Moore, 1965). This trend is known as Moore's Law. (See Figure 2-1) IC's containing thousands of basic components, a complexity level called large scale integration (LSI), began to be used in large quantities around 1970 for computer memories and pocket calculators.

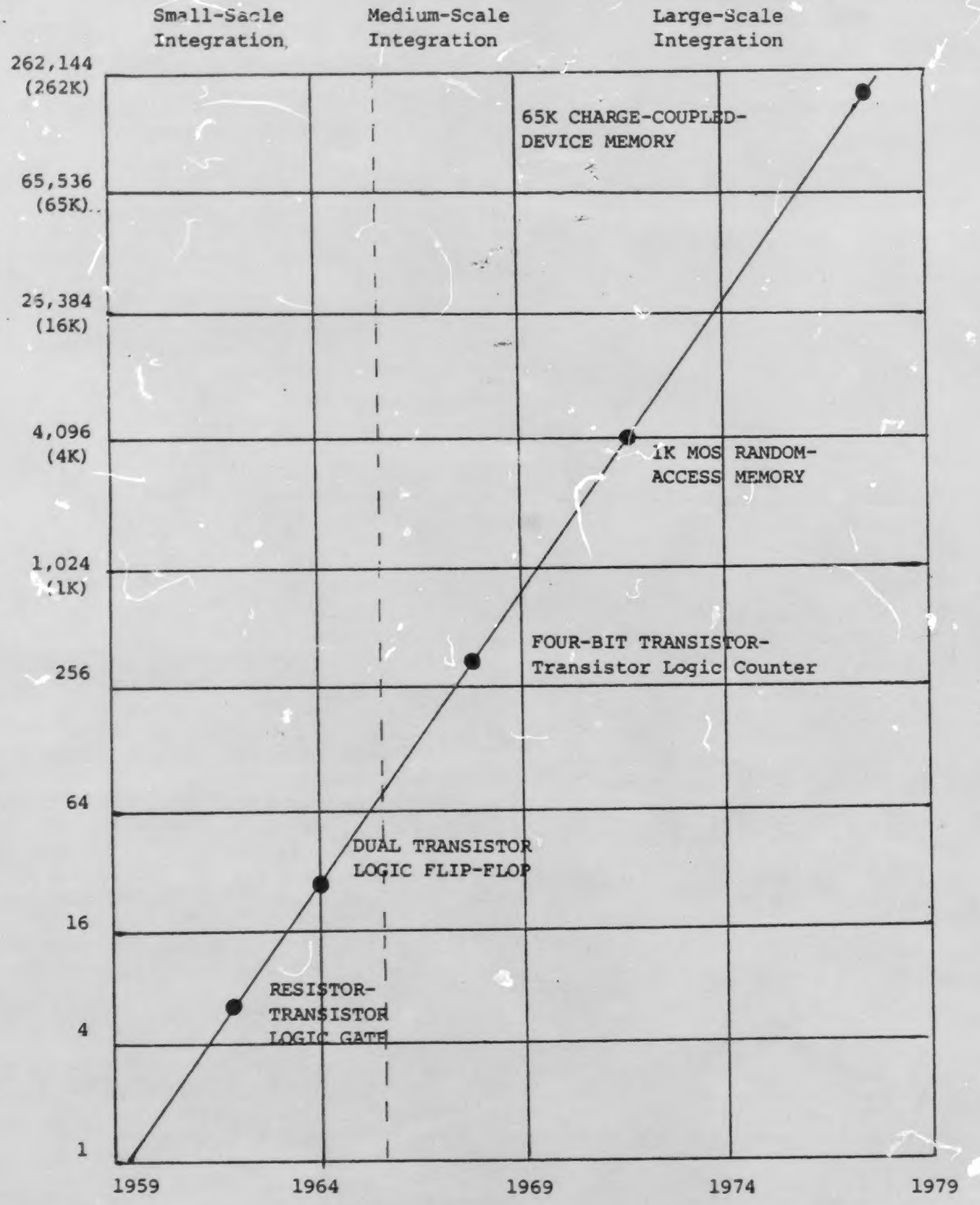
The use of integrated circuits in computers began about 1965 and may be considered to define third generation computers. The most influential computer family introduced then was IBM's System/360 series (Amdahl, *et.al.*, 1964). A measure of its influence is the adoption of System/360 features as standards by other computer manufacturers ranging from Amdahl Corporation's 470 to the Soviet "Riad" series. IBM's current main computer line, the System/370 series, also employs System/360 architecture. Another important development of that period was the minicomputer, a smaller machine with somewhat limited processing abilities but of relatively low cost (in the $10,000 range, at this time). Minicomputers made it feasible to use computers in many new applications such as industrial process control.

Probably the most important advance in IC technology was the introduction of the first microprocessor, the 4004, by Intel Corporation in 1971 (Faggin and Hoff, 1972). A microprocessor is the central processing unit (CPU) of a general purpose computer fabricated on a single IC. Using a microprocessor and a small number of additional IC's, a simple microcomputer can be constructed which weighs only a few ounces and costs less than $100. The introduction of one-chip microcomputers a few years later represents an important milestone in digital technology since it reduces an entire computer (except its peripheral devices which, in most cases, cannot be miniaturized) to a single inexpensive IC. Microcomputers, like mincomputers ten years earlier, enormously increased the range of applications where it is economically feasible to use a computer. One of these applications is the personal computer.

Advances in the technologies used for computer memories and peripheral or input/output devices have been less dramatic. Computer main memories (which require random access capability) were long dominated by ferrite core technology which was introduced about 1950. Developments in LSI have made the ferrite core largely obsolete; most new computers employ semiconductor random access memories (RAM's). Most computers also require a back-up or secondary memory system, which is generally slower, but is lower in cost per bit of information stored. Secondary memory units usually store information in magnetic form on the surface of a mechanically movable medium such as a drum, disk or tape, although punched paper tape is still used as a mass storage medium by many personal computers. While the underlying principles of these devices have remained unchanged, there have been substantial improvements in their cost and performance. The basic form of peripheral devices used for man-machine communication has also been fairly constant. Representative peripherals of this type include teletypes, CRT terminals, line printers, card readers and card punches.

A CPU, such as a microprocessor, executes a specific set of instruction types, which constitutes the machine programming language for the computer in question. Early computers were programmed exclusively in machine language (i.e., in 0's and 1's). Subsequently, assembly language was introduced which allows the use of symbolic names for instructions and data.

FIGURE 2-1



NUMBER OF COMPONENTS PER CIRCUIT

Source: Scientific American, Vol. 237, No. 7, Sept., 1977

Machine and assembly languages are unique to a particular computer or computer family. In the mid-1950's, many high-level machine-independent programming languages were developed which could be run on any computer. A translator program such as a compiler or interpreter converts a high-level language program into machine language before the program is executed. The earliest, and still the most widely used, high-level languages are FORTRAN and COBOL, which are intended for scientific and business applications, respectively. The BASIC (Beginner's All-purpose Symbolic Instruction Code) language, designed at Dartmouth College in the mid-1960's, is a simple programming language which has been adopted as a standard language for personal computers and is currently more frequently used than FORTRAN and COBOL (See Part III). An important recent (circa 1975) programming language is PASCAL.

As computers increased in complexity it became necessary to provide programmers with facilities for program-sharing, file manipulation, processor time-sharing, etc. The necessary system management functions were embodied in a system control program, now usually referred to as an operating system. Operating systems have command languages associated with them which enable a user to specify the services he/she requires from the operating system. These languages, like assembly languages, tend to be computer-specific. The most likely near-term de facto standard, a widely used, machine independent operating system-applications program interface is the CP/M (tm) system developed for Intel microcomputers by Digital Research, Inc.

1.3 Personal Computer Technology

The complexity of a processor is roughly proportional to the length in bits of the basic data items or words that its machine instructions are designed to process. Large "main-frame" computers typically are designed for 32-bit or 64-bit words. A representative word size for a minicomputer is 16 bits, (Although here, too, expansion is occurring. Minicomputers with 32-bit words are appearing.) The first microprocessors, the Intel 4004 and 4040, are 4-bit machines, their small word size relecting the limitations of IC technology circa 1970. They were, however, quickly followed by 8-bit microprocessors from several manufacturers. Of these, the most influential has been the Intel 8080 which was first delivered in 1973 (Intel Corporation, 1975). The 8080 can now be regarded as the progenitor of a family of microprocessors with various degrees of hardware and software compatibility, including the Intel 8085 and 8086, and Zilog Corporation's Z80 and Z8000 series. While 8-bit words are typical of microprocessors, 16-bit machines have also been produced (the 8086, the Z8000 and Texas Instruments 9900 series), a fact which greatly blurs the differences between mini- and microcomputers. In fact, this technological fusion of the two types gives rise to one decision to distinguish between mini- and microcomputers primarily on the basis of system price.

The distinction of being the first mass-produced personal computer (PC) probably belongs to the ALTAIR 8800 marketed in late 1974 by the small Albuquerque-based firm, MITS Inc. Originally sold in kit form, this system received wide publicity resulting from a series of articles in Popular Electronics magazine (Roberts and Yates, 1975). It employed the 8080 microprocessor and sold for about $400 without peripherals; a minimum set of peripheral devices raised the cost of a complete ALTAIR-based computer system to about $2,000. In the next few years, many firms began manufacturing computers for personal use. These companies were, and continue to be for the most part, small entrepreneurial firms. The established computer manufacturers such as IBM and Burroughs have not given any indication that they intend to enter the PC market. Several semiconductor manufacturers, such as Texas Instruments, which supply the IC's used in PCs, have given definite indications of their interest in manufacturing and marketing personal computers.

Early PCs such as the ALTAIR were intended primarily for electronics hobbyists. However, it quickly became apparent that a much larger nonhobbyist market existed for these machines, in such applications as personal financial planning, entertainment, and the management of small businesses. The sale of computers in kit form has greatly diminished (in terms of market fraction), and the number and variety of the hardware and software options available to personal computer users has increased steadily. Prices also have decreased to the point where a complete personal computer with essential peripherals can be purchased today (1980) for about $700.

Figure 2-2 shows the organization of a typical personal computer system. The CPU is designed around a widely-used microprocessor, such as the 8080-compatible Z80, Motorola's 6800 or MOS Technology's 6502, all of which are 8-bit machines. The main memory is organized into 8-bit words, usually called bytes. At least 4K (equals 4096 bytes) of RAM storage are needed for operation of most machines; extra memory may be added in increments to increase the processing capabilities (and cost) of the computer. The CPU and RAM are built from LSI circuits and are usually housed together, sometimes with the keyboard. The peripheral devices used are normally low-cost versions of peripheral types long used in larger computers. Magnetic tape cassettes of the kind used in domestic tape recorders provide a very inexpensive secondary storage medium. Somewhat more expensive, but with faster data transfer capability, is the floppy disk, which resembles a small flexible phonograph record. Keyboard and printing facilities can be combined in the form of an electric (tele-) typewriter. The video display terminal in some systems is a modified domestic television receiver.

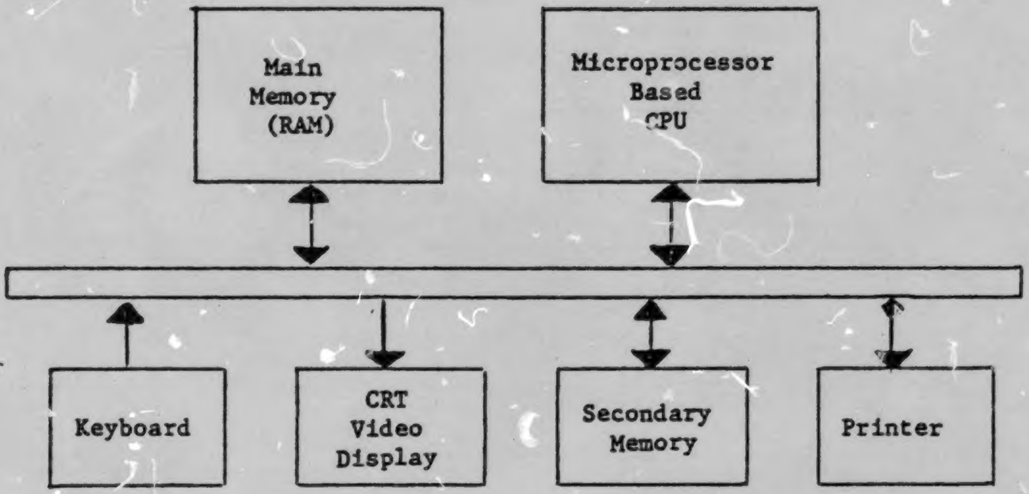
Personal computers are supplied with a rather limited amount of software. BASIC is the most commonly used high-level programming language for several reasons:

1. It is simple and easily learned by nonprogrammers.
2. A working BASIC system can be designed for computers with very small amount of RAM storage.
3. BASIC was established as the programming language of early machines such as the ALTAIR, hence a large amount of software for personal computers written in BASIC already exists.

Disk-based operating systems are found only in the larger, more expensive machines at the present time. Manufacturer-supplied applications programs for the lower priced machines tend to be limited to game-playing routines and personal financial management of the check-book balancing kind. However, many independent suppliers of specialized software packages have arisen, particularly for small business applications.

New hardware or software components can be added to a personal computer if they are compatible with it. Of particular importance in this context is the system interface bus (see Fig. 2-2) which is the collection of lines and signals that allow the peripheral devices to communicate with the CPU or RAM. The personal computer industry has adopted as a de facto standard the S-100 interface bus which was orignally used in the ALTAIR computer. This bus, consisting of 100 lines, has numerous shortcomings in spite of its wide use; it has as yet no official standing (Morrow and Fulmer, 1978). Other standards such as IBM's standard for the format of data stored on floppy disks have been adopted from the established computer industry. There is nevertheless, very little compatibility among personal computer manufacturers. Even the long-established BASIC language is being employed in many mutually incompatible (without translation) dialect versions.

Figure 2-2 A typical personal computer system: (a) hardware (b) software


Main
Memory
(RAM)
Microprocessor
Based
CPU
Keyboard
CRT
Video
Display
Secondary
Memory
Printer

(a)

Operating System

Assembler

Text Editor

High-Level Language Translator(s)

Utility Programs

Common Application Programs

(b)

1.4 Forecasting Methods

In this report, three forecasting methods will be employed which appear to be particularly well-suited to the task at hand.

1. Extrapolation of trends in known technologies.
2. Use of historical analogies.
3. Analysis of user requirements.

The first two methods are examples of exploratory forecasting, while the last method can be regarded as an example of normative (goal-directed) forecasting (Turn, 1974). As is customary in technology forecasts of this nature, a "surprise-free" environment is assumed in that no allowance is made for drastic political or economic changes. Neither is any allowance made for new technologies based on yet undiscovered physical principles or methods of manufacture. It is important to realize that personal computers use only a small fraction of the output of the microprocessor manufacturers. Thus, the PC industry is bound, in its hardware technology at least, to follow manufacturing decisions made to support other requirements and needs. The other needs include automobile ignition systems, microwave ovens, numerically controlled machines and many other "smart" devices.

Trend extrapolation: This type of forecasting assumes that technological progress will continue in a manner that can be predicted from past progress and from known limits on the technologies in question. Some relatively accurate trend extrapolation forecasts have been made for computer hardware technology since the advent of integrated circuits - a good example is Moore's Law cited earlier. Less success has been achieved in predicting the progress of computer software; the difficulty of developing complex new software systems has generally been underestimated.

Historical analogies: Useful analogies can be made between technology trends in the PC industry and trends in other well-established consumer-oriented technologies such as radio and television. Even more fruitful, it seems, are analogies with earlier stages in the evolution of computers. It is clear that as computer technology improves, small inexpensive machines tend to acquire the characteristics of their large more expensive predecessors. The evolution of minicomputers in the period 1965-1975 provides a clear illustration of this historical trend. Many current PCs have the logical organization and the limited hardware and software features of first-generation (1946-1954) computers or early minicomputers. It can therefore be expected (although not with complete confidence) that many of the future improvements in PC technology will involve the addition of features already implemented in large second- and third-generation computers. The past history of the computer industry also provides some useful illustrations of the process by which hardware and software standards are established.

User requirements: As the PC market becomes established, it can be expected that new demands will be made on computer technology. In the likely event that many users will have little or no knowledge of computer programming, simpler means than those used currently must be devised for man-machine communication, e.g., voice input and output. The need for small, cheap mass storage devices can be expected to stimulate the development of technologies such as optical disk memories which might satisfy this need. Forecasts based on user desires must take into account the limits of technology. A flat video (or liquid crystal or semiconductor) display screen of low cost and high quality is clearly more desirable than a CRT as a display device for personal computers. However, over 40 years of research by the television industry have failed to produce a cost-effective replacement for the CRT.

2. INTEGRATED CIRCUITS

Personal computers are a product of developments in large-scale integrated circuit technology during the last 10 years or so. The main characteristic of these developments has been a steady increase in the maximum number of components in a single IC chip, while the cost of an IC of maximum complexity has remained approximately constant (see Figures 2-3 and 2-4). IC's are used to build the following components of PCs:

1. Central processing unit (CPU), usually a microprocessor;
2. Memory, including random access memory (RAM) and read-only memory (ROM); and
3. Special-purpose processors, including arithmetic and communication processors, and I/O device controllers.

These functions are frequently combined in various ways in a single IC chip. The processing speed and capacity of a PC are determined primarily by its CPU and main memory.

2.1 Physical Characteristics

Introduction: Integrated circuits are produced using many different technologies which are distinguished by the manufacturing techniques employed and the physical behavior of the resulting IC's. IC's can be separated into two broad classes: bipolar and MOS devices, which differ in the polarity of the electrical charges of the current carriers employed. Bipolar circuits, as their name implies, use both positive carriers of electric charge (holes), and negative carriers (electrons). In MOS devices only one type of charge carrier is used; the name MOS (metal oxide semiconductor) is derived from the materials used to fabricate MOS circuits. MOS IC's are generally smaller, consume less power, but are slower than equivalent bipolar devices. MOS and bipolar technologies are continually evolving to meet the goal of higher performance per IC chip.

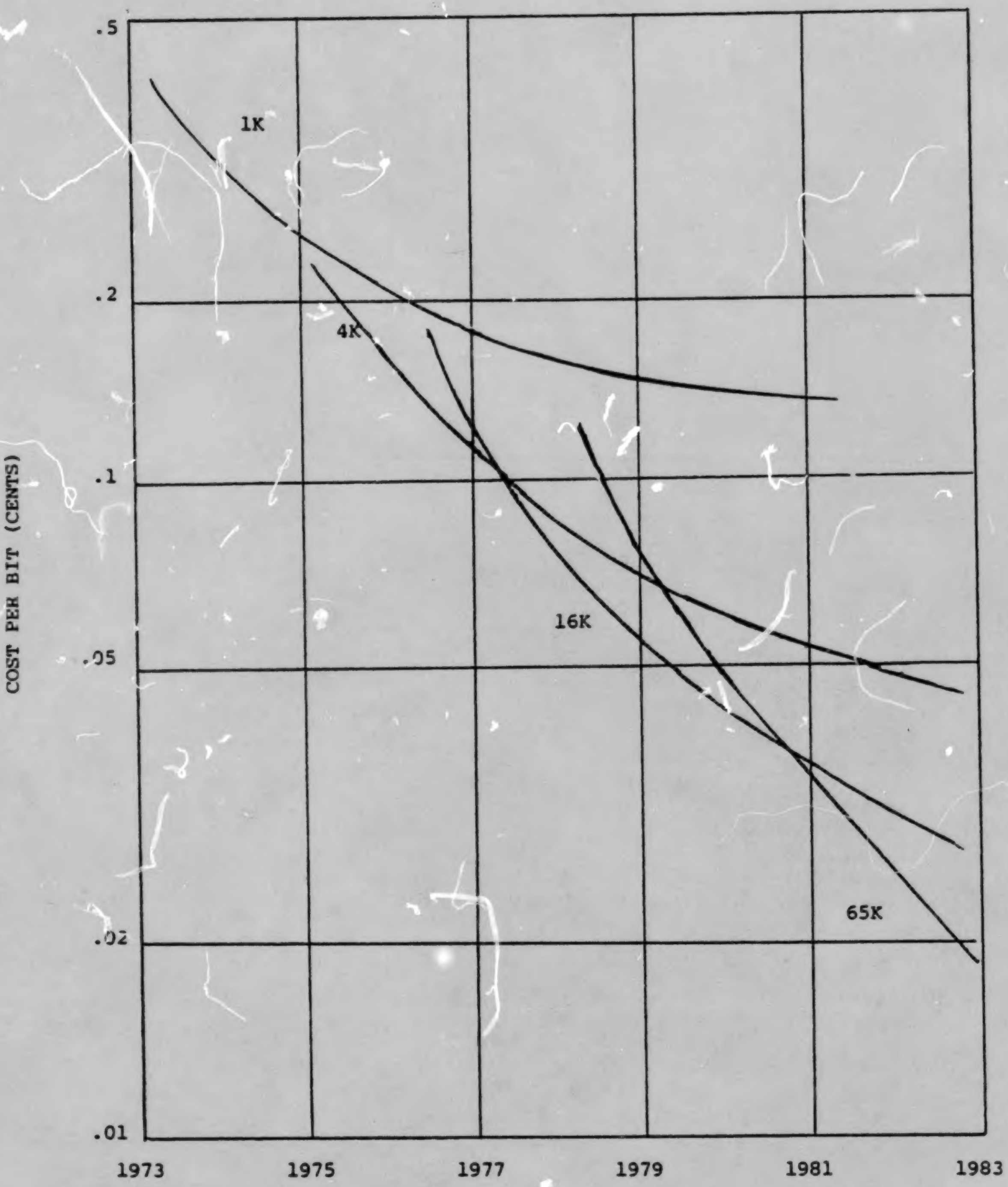
The manufacturer of an IC involves a series of steps in which a single piece of silicon is transformed layer by layer into the required circuit. A typical step involves the use of a mask to specify the regions on the surface of the silicon to be transformed by such operations as photographic exposure, etching, diffusion, etc. The entire process can be viewed as a kind of photoengraving, where design cost is determined by the number and complexity of the masks used. After manufacture, IC chips are typically housed in packages such as DIP's (dual in-line packages) which are rectangular in shape, and contain two parallel runs of pins for connecting the IC to the outside world. A microprocessor is often packaged in a 40-pin DIP, although DIP's with up to 64 pins are used.

The characteristics of IC's most relevant to PCs are as follows:

1. Component density per chip;
2. Speed of operation;
3. Reliability.

Component density is determined by the dimensions of the components (transistors, connectors, etc.), and has tended to increase steadily with improvements in manufacturing methods. **Speed** is also increased by reducing component dimensions, but is primarily a function of the electronic circuit technology used. Power consumption and, therefore, heat dissipation problems tend to increase with the speed of an IC circuit. In many cases, power requirements limit the component density of an IC. Another limitation is

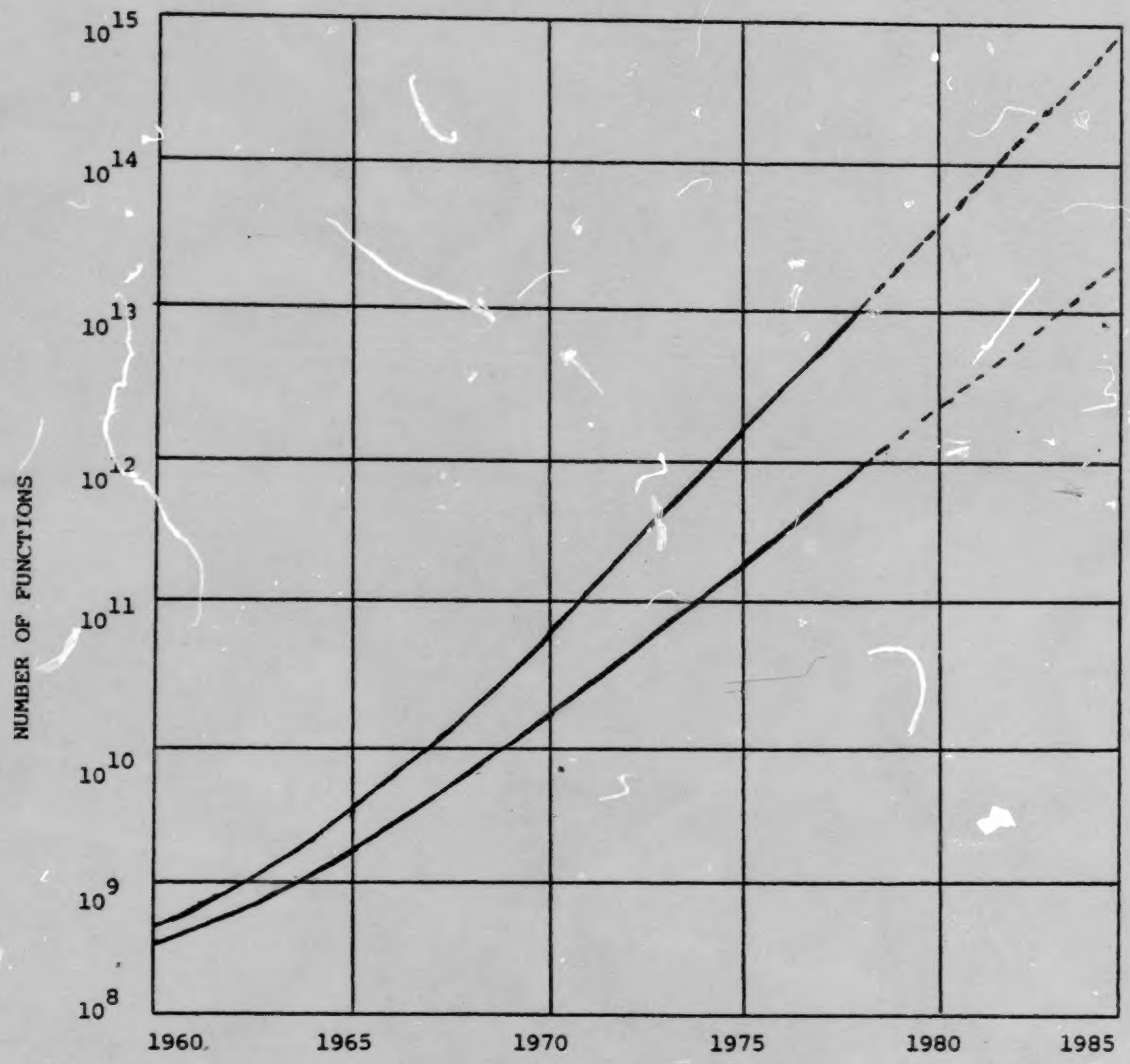
FIGURE 2-3



COST PER BIT OF COMPUTER MEMORY

[Source: Scientific American, November, 1977]

FIGURE 2-4



ANNUAL UTILIZATION OF ELECTRONIC FUNCTIONS

[Source: Scientific American, November, 1977.]

imposed by pin requirements. It is often impractical or too costly to manufacture in a single IC a system that requires a large number (100 or more) of external connections. The **reliability** of a system is roughly proportional to the number of IC chips it contains. Thus, as component density per chip increases, system reliability can be expected to improve. A limiting factor here may be the cost of testing the chips during manufacture.

Forecast: The steady increase in LSI chip density which has occurred in the past decade is expected to continue for the foreseeable future (provided that market conditions are such that demand for increasingly complex IC's continues to exceed the supply). Although the limits of photolithography are now being approached (i.e., the minimum dimensions of IC components are approaching the wavelength of light), light can be replaced in the manufacturing process by electrons (E-beam lithography) or X-rays. Both E-beam and X-ray lithography are reasonably well understood at the present time. There appear to be no insurmountable obstacles to the production of VLSI circuits (Very Large Scale Integration: 100,000 or more components per chip) by the mid-1980's (Hazan, 1977; Capece, 1978).

There is likely to be relatively little demand for very-high speed IC's for use in PCs because of the decrease in the achievable component densities, and the increase in environment control they entail. Thus, emitter-coupled logic (ECL), which allows subnanosecond switching speeds and is currently used in some large supercomputers, is not expected to be used in PCs, because it requires expensive cooling methods, such as direct refrigeration. Faster devices based on the Josephson effect are now being developed; these are even less suitable for PCs because they function only at extremely low temperatures (in the order of a few degrees above absolute zero).

Personal computers are not expected to be a driving force toward advancing the state-of-the-art of IC technology. Rather they are expected to benefit from developments occurring in the semiconductor industry that are aimed at a broad range of applications. In particular, PCs will benefit from a substantial increase in the performance/cost ratio resulting from VLSI. This will lead to personal computers containing IC's that are fewer in number and have more processing ability than their predecessors. Little increase in the basic switching speed of PCs is expected. Increases in overall processing speed will, however, result from new designs in which longer word sizes are used, and more functions, e.g., floating-point arithmetic, are performed by hardware instead of software. These considerations are discussed in detail in the following sections.

As the number of components in a IC chip increases, so does the difficulty of testing the chip, both during manufacture and subseqently during field maintenance. Conventional testing of such chips requires equipment beyond the resources of PC users and, indeed, many PC servicing companies. The problem , in principle, can be largely alleviated by building test circuits and programs into a PC so that it can test itself. We predict that self-testing capabilities will be incorporated into PCs by the late 1980's. The use of redundant circuits to improve reliability can also be expected to spread to PCs as they are applied to such sensitive areas as household security control.

2.2 Microprocessors

The CPU of a PC is a microprocessor. The type of microprocessor used has some extremely important consequences.

1. It determines the machine language of the PC.
2. It determines the system interface bus.

3. It partly determines the speed of the computer.

As discussed in Section 1.3, machine languages and interface buses are the main factors governing compatibility at the system level. Thus, software is often distributed in machine language form, and is therefore microprocessor-specific. Most peripheral devices are designed for direct connection to the system interface bus of a specific type of microprocessor.

A typical microprocessor contains a small set of "registers," which functions as a temporary or scratchpad memory, and the necessary logic to execute a repertoire of about 100 instructions. These instructions perform arithmetic operations on numerical data, nonnumerical operations such as program branching and logical operations, data transfers between the microprocessor and RAM, and data transfers between the microprocessor and peripheral devices. The operands used by machine instructions are relatively short, 8 bits being typical. The hardware-implemented arithmetic operations are invariably limited to fixed-point numbers, and may not include multiplication or division. Thus extensive programming is often needed to execute common operations that can be implemented by single instructions in large computers.

Forecast: The number of different microprocessor types used for personal computers is not expected to increase significantly over the present levels, primarily because of compatibility considerations. As the body of available PC software grows, the tendency to adhere to well-established machine architectures is likely to accelerate. A graphic analogy is found in the large computer field where the 15-year old IBM System/360 architecture continues to dominate general-purpose data processing. Even though many aspects of the design of System/360 are now obsolete (Bell and Newell, 1971) it has been possible to build computers that take advantage of technology improvements and still maintain compatibility with System/360.

The architectures used for microprocessors in PCs are likely to fall into two main groups:

1. Microprocessors that are compatible with existing well-established microprocessor families.
2. Microprocessors that are compatible with existing large computers such as System/360 or with established minicomputers, including microprocessor-based minis such as the RSI-1 and the MicroNova.

The most widely used microprocessor family not derived from a large computer is the 8080 family originated by Intel. The members of that family, which have varying degrees of compatibility include the Intel 8085 and 8086, as well as the Zilog Corporation Z80 and Z8000 series. Because of its wide use in PCs, this family is expected to continue to be a standard for PCs. Other current microprocessor families expected to remain in wide use are those based on the MOS Technology 6502 and the Motorola 6800. It is expected that these families will be augmented regularly with newer members that provide additional functions. For example, the 8086 extends the instruction repertoire of the 8080 to include 16-bit instructions (Intel, 1978), with an analogous transition between the Z8000 and the Z80, and the 68000 and the 6800.

It is expected that PC microprocessors will eventually acquire all the major features of large third generation computers, including floating-point arithmetic circuits, virtual memory and powerful operating systems. Since the necessary hardware and software designs exist, the limiting factor is CPU and RAM cost. As VLSI lowers the cost of these components, it will then become feasible to put, say, the Cray I on a single IC. An analogous evolutionary process has taken place in minicomputers, which now have most of the features of earlier, large machines. Already some relatively large minicomputers such as the DEC PDP-11 exist in microcomputer versions. Since 1977, Heathkit has been marketing a personal computer system, the H11A, that uses the LSI-11 16-bit microprocessor which is compatible with the PDP-11. The rate at which these earlier architectures appear in PCs will probably be determined by the availability of software for those machines, a fact which is useful to PC owners.

2.3 Memories

The success of IC technology can best be measured by the component densities achieved for semiconductor memory chips (ROM's and RAM's). These devices contain a large number of simple components (1-bit storage cells) arranged as a uniform array; they are therefore relatively easy to manufacture. Furthermore, since a chip storing n words requires only log(n) [logarithm to the base 2] address lines, pin count is not a problem. (For example, a chip storing 1024 bits requires log(1024) = 10 address lines.) RAM chip capacity has increased from 1K = 1024 bits in 1972 to 64K bits in 1978. ["64K" is actually 65,536 (2^{16}). Computer parlance uses the shorter, but less accurate, term for brevity.] Maximum ROM chip capacities have been approximately double these figures. ROM's and RAM's are used to build the main memory of a PC which stores the instructions and data required during the actual operation of the computer. It is augmented by a secondary (non IC) memory which stores information not in active use.

Forecast: Semiconductor memory chip capacity is expected to increase steadily into the mid-1980's. The figure of one megabit (2^{20} bits) should be reached by then. The prospects for significant further increases are uncertain, however (Capece, 1978). Since the maximum main memory requirements of most current microprocessors is 64K bytes (2^{16} bits), corresponding to a maximum of 16 address lines, it is expected that many PCs in the mid-1980's will have main memory on a single chip (which may also contain the CPU).

It is anticipated that ROM's containing systems programs, such as compilers, interpreters and operating systems, will be widely available in the 1980's. These will enable the PC user to bypass the software interface problems commonly associated with using those programs, since it will no longer be necessary to transfer them into RAM from secondary memory before execution. Indeed, high-capacity ROM's offer the ability to wire a large number of special functions into a PC at relatively low cost.

Several design techniques are known for increasing the speed and flexibility of computer memories, including the use of virtual memories, caches and associative addressing (Hayes, 1978). Until recently, these techniques were confined to a few large systems because of the high hardware costs involved. We expect to see their use become widespread in PCs. Associative or content-addressable memories have the advantage of greatly simplifying the programming of many information storage and retrieval tasks. Semionics Associates, a small Berkeley firm, is currently selling an add-on "recognition" memory for PCs that uses associative addressing (Lamb, 1978).

2.4 Special-Purpose Processors

Traditionally, all significant processing tasks in a computer are carried out in the CPU. The advent of LSI makes it feasible to build low-cost processors to which the CPU can delegate some of its functions, for example:

1. The execution of complex algorithms such as those required for floating-point arithmetic, graphics or speech processing.
2. The supervision of input/output operations including the tasks of interfacing with peripherals.

Already a small number of arithmetic processors to augment standard microprocessors are being marketed (Smith, 1978). The Advanced Micro Devices 9511 chip, for instance, executes all the functions normally found in a 32-bit scientific calculator. It interfaces directly with the 8080 microprocessor so that, in effect, it extends the 8080 instruction set to that of a much larger computer. Such processors can be regarded as hardware-implemented scientific subroutine packages.

Several of the major microprocessor families include 1-chip controllers for many common peripheral devices and interface buses. For example, the recent 8086 family includes controllers for floppy disk units, CRT displays, keyboards and matrix printers (Beaston, 1978; Intel, 1978). Interface chips are available to match the 8086 with the IEEE Standard 488 instrumentation interface bus and the IBM SDLC communications interface. There are also programmable interface chips like th Intel 8255 which can be programmed to perform many different control tasks. In some instances it may be useful to use microprocessors to control specific input/output functions, so that with the CPU, the computer system constitutes a loosely-coupled multiprocessor (Faggin, 1978). This approach has been strongly advocated by Fairchild for their F8 microprocessor (Fairchild, 1976).

Forecast: Special-purpose processors that can be added to existing systems are a particularly attractive way of increasing the power and applications range of a personal computer. They are faster than equivalent software routines, and they do not occupy RAM space. We expect that IC's of this kind will be increasingly used in the following PC applications:

1. Controlling of individual peripheral devices such as displays, keyboards, printers, and household appliances.
2. Matching PCs to different interface bus types.
3. Controlling the interfacing tasks associated with long-distance communication via telephone lines or radio.
4. Execution of special-purpose algorithms for such tasks as speech recognition and synthesis, audio signal processing (digital recording), picture processing, scientific and financial computation, and game-playing.

3. PERIPHERAL DEVICES

Peripheral or input/output devices are among the most expensive components of a personal computer. A large variety of such devices exists, and their cost and quality vary greatly. Because most computer peripherals contain electromechanical parts, they have not benefited significantly from the cost reductions created by LSI. Their reliability is also adversely affected by their partly mechanical nature. Many input/output functions such as flexible voice control of value to PC users are not generally available. Other desirable devices such as high-quality printers are readily available, but they are too expensive for many users. Thus, there is a rather wide gap between PC user needs and the ability of the peripheral supply industry to satisfy those needs.

It is convenient to divide PC peripherals into three broad groups:

1. Secondary storage.
2. Standard input/output devices.
3. Nonstandard input/output devices.

The present status and future prospects of these three groups are examined in the following sections.

3.1 Secondary Storage

Secondary memories serve as back-up memories for a computer (see Figure 2-5). They are designed to use low-cost portable storage media, and thus serve as a means for transferring large programs or data sets to main memory. Currently, the usual secondary storage devices in a PC are magnetic tape cassette recorders, "hard" and floppy disk units which employ rotating magnetic disks. Limited use is also made of semiconductor ROM chips (see Sec. 2.3) and punched paper tape. Magnetic tape and disk units represent relatively mature technologies. Nevertheless, they are undergoing continual refinement in an effort to reduce the cost per bit of information stored. Several newer technologies, notably magnetic bubble and optical disk memories, are also being developed which are likely to be used in PCs in the early 1980's.

Disk memories: Disk memories are of two general types: "floppy" and "hard" disks. A floppy disk memory consists of a disk of flexible plastic with a coating of magnetic material on one or both surfaces. Information is stored in concentric, magnetized tracks on the surface of the disk. During operation the floppy disk is rotated at high speed (typically 300 rpm) by an electric "drive" motor, and data is transferred to or from the tracks via a read-write head that can be moved radially across the disk surface. The floppy disk drive unit therefore resembles a phonograph with the floppy disks corresponding to phonograph records. Several floppy disk drives may be combined into a single multidrive unit.

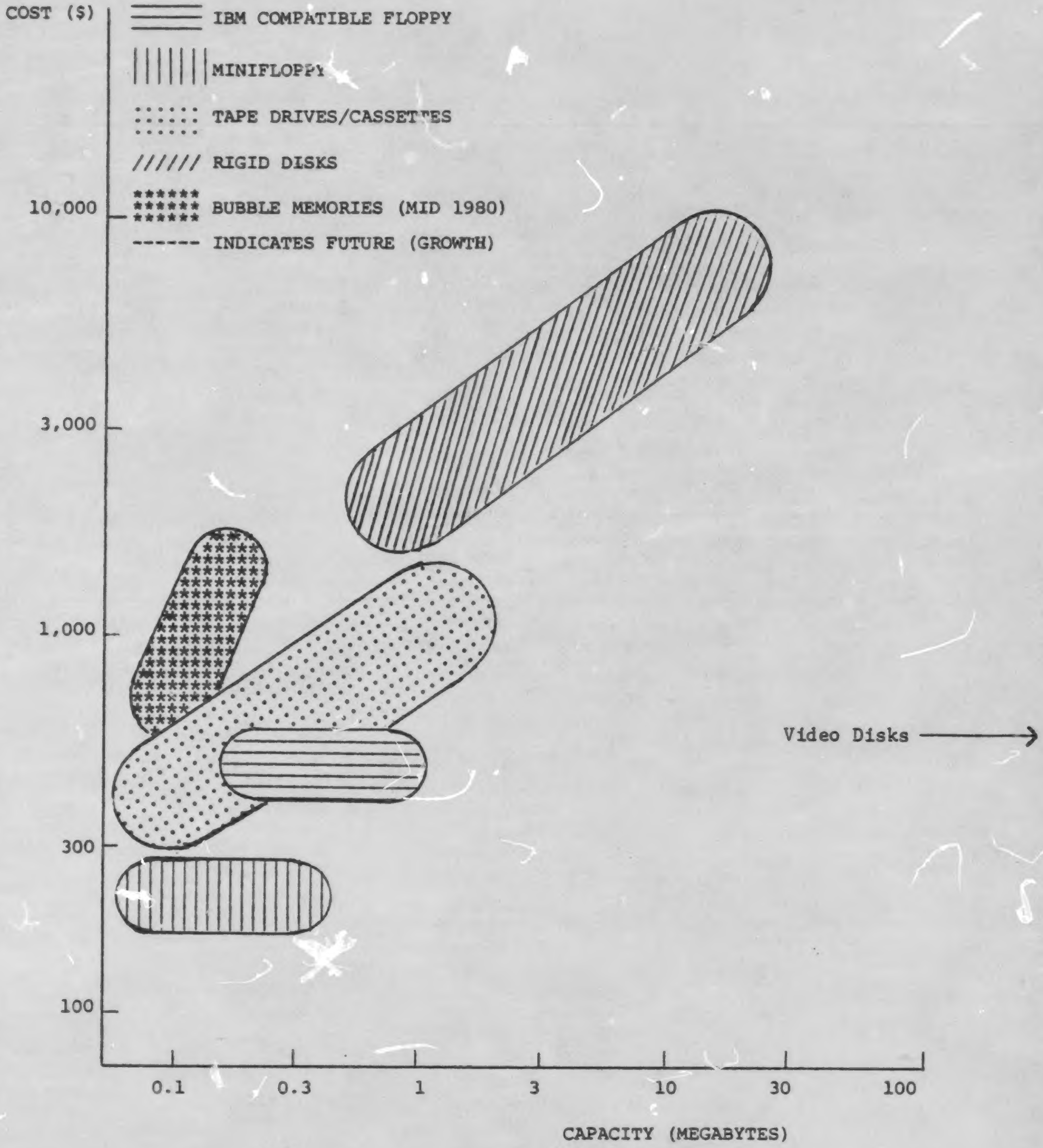
Floppy disks are manufactured in two standard diameters, 8 inches and 5.25 inches. The storage capacity varies greatly depending on the formats used for the stored data. Formatting considerations include: the density of the stored information along the tracks, the number of sections into which each track is subdivided for addressing purposes, and the hardware and software conventions for interfacing with the disk. Disk storage capacity typically ranges from 100K to 1M bytes. The most widely used format, the IBM 3740 standard, allows approximately 256K bytes to be stored on one side of an 8-in. diameter floppy disk.

The performance of a floppy disk unit can be measured by its data transfer rate, which typically is in the range 15.6K to 62.5K bytes/second. The maximum time to access a (random) word varies from about 0.2 to 2.5 seconds. Complete floppy disk units range in cost from about $500 to over $3,000. An example of a low-cost system for PCs is Apple Computer's model AZM0004 disk system which provides 116K bytes of storage using a single drive unit, and costs $595; it is compatible only with the Apple II computer. The cost of a blank floppy disk is a few dollars.

Hard disk memories operate on essentially the same principle as floppy disks. However, because the disk substrate, upon which the magnetic material is coated, is made of a hard, stable material such as aluminum much greater precision in data location can be achieved. Consequently, much higher data packing densities can be attained on a hard disk. As an example of the most advanced technology, hard disk systems, using IBM developed "Winchester" technology, with storage capacity in the order of 30 million bytes are expected to be available in PC systems in mid-1979 and at a cost about seven times that of a floppy disk system which provides less than 10% of the on-line storage capacity. In mid-1980 mini-Winchester hard disks (5.25 in., or 210 mm., diameter) were becoming available, storing 5 Million bytes or more at a cost comparable to that of a large floppy disk drive.

Furthermore, because hard disks can be enclosed in sealed containers, the systems are much less vulnerable to environmental hazards (dust, dirt,

FIGURE 2-5



COST VS. CAPACITY FOR VARIOUS MEMORY TECHNOLOGIES

[Source: *Mini-Micro Systems*, November, 1978.]
(adapted version)

moisture) than floppies. Thus, their reliability and useful lifetime tend to be higher by a factor of two or more. They can be run at higher speeds, with correspondingly decreased access times. Some hard disks are packaged in cartridges and are transportable from system to system as are floppy disks.

Forecast: Floppy disk memories use essentially the same technology as "hard" disk memories which have been produced commercially since the mid-1950's. The relatively long evolution of disk memories has resulted in a steady increase in performance and storage capacity, as well as a steady decrease in cost and physical size. This improvement is likely to continue for the foreseeable future. Furthermore, improvements in technology are likely to extend the usefulness of current disk memory devices, rather than render them obsolete (Steifel, 1978).

It is probable that some, but by no means all, current applications of disk memories will be taken over by bubble memories by the mid-1980's. Bubble memories are inherently more reliable than disk or tape memories, since they contain no moving parts. Like floppy disks they are compact and nonvolatile, and can be designed to give comparable performance. The cost per bit of bubble memories will probably remain much higher than that of disks, and hence the latter will be preferred in applications where large amounts of information must be stored off-line. In those PC applications requiring extremely large stores, video cassette and optical disk recorders are possible candidates.

Cassette tape memories: These memories operate on the same principles as domestic tape recorders; indeed, the latter are often modified for use as secondary memory units in personal computers. Tape cassette recorders are cheaper (Radio Shack's TRS-80 system cassette recorder costs $50) and more compact than floppy disk units, but their data transfer rates are much slower. It can take minutes to transfer a lengthy file between main memory and a tape units. The same transfer takes only a few seconds if floppy disks are used. Standardization of magnetic tape data storage formats is also lacking.

Forecast: As a mature, inexpensive and widely used technology, magnetic tapes are expected to maintain their position as the secondary memories of choice in the least expensive PCs. No major change in cassette tape technology is likely, although increases in storage densities and data transfer rates can be expected. It is also possible that video cassette recorder (VCR) technology will be applied to PCs. VCR's costing less than $1,000 have been widely sold since 1977. As they proliferate, their incorporation into PC systems is a strong possibility. A VCR, for example, would allow the inclusion of high quality graphics in computer games. Current video games typically display only crude stick figures. Competition for VCR's is likely to come from optical disk memories.

Optical disk memories: Several technologies are currently in the final stages of development which use plastic disks resembling phonograph records that can be read or written on using optical techniques. In a typical system of this kind the disk is rotated at a constant (or head radius dependent, in some versions) speed as in a floppy or hard disk unit, and a laser is used to inscribe (by burning or melting) data along a track. The data can be subsequently read by projecting a laser beam onto the track. Optical disks offer extremely high storage capacity (10 billion bits can be stored on a 12-in. disk developed by Philips) and fast access rates. Optical disk units are becoming broadly available for use as video recorders for domestic television sets. In mid-1979 in a test of the videodisk market by Magnavox/MCA in Atlanta, Georgia, the supply of disks and playback units was sold out in minutes.

Forecast: The main attraction of optical memories is the low cost of mass-produced prerecorded disks. Their enormous storage capacity makes them suitable as archival stores. For example, over 600,000 pages of printed text could be recorded on a single optical disk. It appears, however, that relatively few PC owners will need memories of this capacity for program or data storage, floppy disks and tape cassettes being adequate for most purposes. If optical disk recorders are successful in the television market, they are likely to be coupled with PCs to provide high-quality video images for computer-based games and interactive educational activities. In this area, optical disks will compete with video cassette recorders which, unlike optical disk recorders, are already being mass-produced.

One further potential application is the storage of a large reference work, such as an encyclopedia, or collection of works on an optical disk. The current edition of the Encyclopedia Brittanica contains about 250 million bytes - only enough to partially fill a Philips 12 inch disk if the material were confined to text information alone (i.e., excluding pictures). The disk could incorporate sophisticated course referencing software so that the user could rapidly locate any desired item or collection of information for display. Unit costs of production of the disks could be considerably less than production of printed books, although fixed costs of production (reference data assembly plus added referencing software) would tend to be higher.

Bubble memories: Magnetic bubbles, which were discovered around 1970, are tiny cylindrical magnetic domains which can be created in thin sheets of certain materials such as garnet by an external magnetic field (the bias field). If a second rotating magnetic field (the drive field) is applied, the bubbles can be made to move rapidly along predetermined paths. Magnetic bubble memories can then be formed by streams of continuously moving bubbles, where the presence or absence of a bubble represents a stored 0 or 1. Unlike the secondary memory devices discussed so far, bubble memories involve no mechanical motion. Furthermore, they are manufactured by processes similar to those used to make semiconductor IC's. Bubble memories have the potential for providing reliable, compact devices with storage capacities and operating speeds comparable to floppy disk memories (Pugh, 1978).

Bubble memories reached the marketplace in 1977 in voice recorders (Western Digital) and portable computer terminals (Texas Instruments). Bubble memory chips storing 92,304 bits are presently available for about $100 each. However, like semiconductor IC technology, the manufacture of bubble memory chips is likely to experience a steep "learning curve" that will result in much lower costs per bit and much bigger capacities per chip. Already one-megabit bubble memory chips have been developed and will probably be marketed by 1980. Chips with a quarter of a megabit capacity were announced in 1978 by Rockwell and Texas Instruments. It is significant that several major suppliers of IC's to the PC industry, including Intel and National Semiconductor, have recently initiated programs to manufacture bubble memory chips.

Forecast: The cost of a bubble memory chip is at present greater by a fraction of 1000 or so than that of a comparable amount of floppy disk memory. This factor will decrease substantially as bubble memory technology improves. However, bubble memory chips by themselves (with a small amount of electronic interface circuitry) can form complete memory systems, whereas floppy disk memories require expensive and bulky mechanical drive units. Hence, there is a greater initial cost or overhead associated with floppy disk and other electromechanical memories, which is absent from bubble memory systems. This gives bubble memories a significant advantage in certain applications such as storing a medium-sized operating system in a PC. On the other hand, bubble systems are not so easily transportable, as are floppy disks and tape cassettes, and thus are not so convenient as media for software transfer. It is probable that floppy disk systems will continue to be preferred in applications requiring inexpensive off-line storage of relatively large amounts of information until more compact, "plug-in" bubble modules are developed.

Bubble memories can be organized in various ways to increase their effective data transfer rate, thus enabling them to occupy an intermediate position between main memories and conventional secondary memories. Hence, a possible future role of bubble memories is as a buffer between semiconductor RAM's and slower and cheaper memories such as disk or tape units. In some cases, a bubble memory may be suitable for use as a computer's main memory, since bubble devices, unlike most semiconductor RAM's, are nonvolatile, that is, the stored information is not lost when the power supply to the memory is switched off.

CCD memories: A charge coupled device (CCD) memory is a semicondconductor IC organized as a shift register, in which information is represented by packets of electrically charged particles, normally electrons. These packets are circulated continuously through the shift register by an electric drive field, in much the same way as bubbles circulate through a bubble memory. The storage capacities and operating speeds of CCD memories are comparable to those of bubble memories. 64K CCD memory chips are currently available, while 256K chips are in the offing. CCDs are seens as possible replacements for disk memories. Unlike bubble devices they are relatively easy to interface with standard semiconductor ICs.

Forecast: CCD manufacturers appear to have encountered serious difficulties, both in production and market acceptance of their products. Several of them, notably Intel, have discontinued the manufacture of CCD memories. At present only two major manufacturers of CCD memories remain: Fairchild and Texas Instruments. CCD memories are clearly experiencing stiff competition from bubble memories, and also from semiconductor RAMs, whose capacities are now approaching those of CCD chips. While there are certain applications for which CCD memories are especially suited, e.g., image processing applications where CCD imagining devices are used, the future of CCD memories in the general computer market is very uncertain.

3.2 Standard Input/Output Devices

Most PCs include several devices for direct communication between the computer and a human operator, such as a keyboard, a video display unit and a hard-copy printer. These peripherals may be termed standard since they are also found in most large computer systems, and have been in use in various forms since the earliest days of the electronic computer era. The keyboard (input), display (evanescent output) and printer (permanent output) functions may be combined in various ways. For example, a teletype combines a keyboard with a hard-copy printer, while a CRT terminal combines a keyboard and a video monitor. Other input/output methods such as voice control are considered in Sec. 3.3.

Keyboards: Keyboard terminals for computers fall into two groups: those with standard typewriter-like alphameric key layout, and those with special layouts of the kind found in pocket calculators. In each case, there is a set of keys controlling on-off switches. The states of the switches are processed by electronic circuits which eliminate signal noise (such as switch bounce) and generate character codes in binary form, the 8-bit ASCII code being most widely used in PCs. LSI has reduced keyboard control logic to one or two IC's Typewriter-style keyboards are available for as little as $50 in kit form. No significant change in keyboard technology is seen affecting PCs. Light pens, which may be used to augment keyboard functions, are examined in Sec. 3.3.

Video displays: The primary purposes of a video display in a PC are to display textual material such as lists of data, and graphical images such as charts, game boards and the like. Almost all current PCs use a cathode ray tube (CRT) which is either part of the PC, or is provided by an ordinary TV receiver. Character images for text display are obtained from a ROM chip that stores the characters in digitized form. Graphical images usually require additional memory space and graphics software packages that may be quite complex and costly. Terminals containing a small CRT and a keyboard, and having no graphics capability, cost $300 or more. When a very small amount of information must be displayed, e.g., a single line of code on a computer's front panel, light-emitting diode (LED) displays are used.

Forecast: The CRT has undergone continuous development for about 50 years. It has obvious disadvantages. It is bulky, fragile and expensive. It also requires complex support circuitry and high voltages. Nevertheless, we foresee the CRT's continuing to be the main display device for PCs. The existence of vast numbers of domestic TV receivers will ensure the availability of CRT's for the foreseeable future. Furthermore, potential competing technologies seem to be considerably less cost-effective for PC applications than CRT's. A noteworthy example is the plasma display panel developed in the early 1960's. This is a flat, flicker-free display device which allows high data transfer rates. However, it is also very expensive, monochromatic, and requires complex support circuitry. Plasma display panels can be found in some applications such as stock quotation devices and may find limited use in PCs.

Printers: Printing speed and quality tend to be inversely related to manufacturing cost; hence many different technologies have been developed for hard-copy printers which provide various compromises between printing performance and cost. All printers contain some mechanical components such as a paper feed mechanism which contribute substantially to their cost. Printers may be classifed by various features of their construction.

(1) The character-forming device used: Many printers use type elements with a fixed set of completely-formed characters. These preformed characters may be on individual typing bars as in standard typewriters, on a single cylinder as in a teletype, on a ball as in an IBM Selectric typewriter, on a multispoked, daisy-shaped wheel as in Xerox/Diablo and Qume printers, on a multispoked "thimble" as in Nippon Electric Co. printers, or on a belt or chain as in many line printers. Another class of printer uses a single print head capable of printing a dot matrix; typical matrix size is 5x7 or 7x9 dots. By selecting the dots to be printed, a wide range of characters can be formed, although they are often of poor quality.

(2) The inking method employed: Many printers use inked ribbons interposed between the print head and the paper. An impact mechanism brings the print head and the paper together causing ink to be transferred to the paper. Some low-cost printers use a thermal printing process in which heat-sensitive dyes are embedded in the paper used, and the print head (usually of the dot matrix type) heats the parts of the paper where an image is desired. Electrostatic printing methods such as xerography are also used. More recently ink jet printing technology has been under development in which

tiny ink droplets are projected from a reservoir to form the desired pattern on the paper. (Kuhn, 1979) Lasers are also used as the image-forming means in some expensive printers.

(3) Printing speed: The least expensive units are serial printers which print one character at a time. Printing rates range from about 10 cps (characters per second) to 120 cps. Line printers print an entire line at a time at rates from 10 lines per second or more. Printers capable of printing a page at a time also exist.

Table 2-2 illustrates the important characteristics of four types of printers that are often found in PC systems. For this market, low cost is probably the main consideration, while high speed is relatively unimportant. PC printers range in cost from about $400 to $3000. An example of a low-cost printer is the Radio Shack Quick-Printer for the TRS-80 personal computer which cost $499 in December, 1978. It uses an inexpensive electrostatic printing process that requires aluminum-coated paper. Characters are formed by a 5x8 dot matrix and are printed in lines of up to 80 characters at a speed of 150 lines per minute.

Forecast: We anticipate continued refinement of all currently-used printing technologies with the goals of improving printing quality and lowering printer cost. The least expensive printers will find their main market in domestic applications where hard-copy is required but quality is unimportant, such as records of financial transactions, or the results of PC-based games. Higher quality printing will be required in PCs used for business applications.

A relatively inexpensive way of obtaining high-quality printing would be to produce the equivalent of a standard electric typewriter as a computer peripheral. Because of the problem of mechanized complexity, it is unlikely that these typewriters would resemble contemporary, inexpensive electric typewriters. It is more likely that they would use a dot-matrix printing technique, probably with electrostatic printing. This latter approach would be particularly attractive if a technique is developed to print electrostatically without the need for specially coated paper. The fact that they can also serve as ordinary typewriters makes such devices particularly attractive in environments where typewriters are ordinarily used. The PC can be used to enhance the typing process by providing such facilities as text editing and memory. Since good-quality portable, hard-font electric typewriters now cost as little as $200, it is probable that PC printing terminals based on dot-matrix printers would, if mass-produced, cost around $300.

3.3 Nonstandard Input/Output Devices

Many PC owners are likely to find standard I/O devices too complex or inconvenient for many routine tasks. This is particularly true of physically handicapped users. We, therefore, must consider some other ways by which computers and humans can communicate. Two approaches seem most promising:

1. Voice communication; and
2. Communication via visual images on a display device.

The ability to input information via handwritten documents might also be desirable but presents major technological problems which are likely to keep costs high for the foreseeable future. Another group of I/O devices considered here are those that enable a PC to control specific devices such as household appliances.

Table 2-2. Characteristics of some representative hard-copy printers.

Printer Type	Impact with performed characters	Impact with dot matrix	Electrostatic with dot matrix	Thermal with dot matrix
Printing quality	good	fair	fair	fair
Speed	slow	moderate	fast	moderate
Cost	moderate	high	low	moderate
Noise	high	moderate	low	low
Graphics quality	poor	moderate	good	good
Requires special paper?	no	no	yes	yes

Voice Communication: There are two aspects to voice communication with a computer: speech recognition and speech synthesis. Of these two problems, that of speech recognition is the more difficult. Nevertheless, a number of PCs already are capable of a limited amount of voice communication with their human operators (Boddie,1977).

Speech processing for personal computers is most often based on the use of phonemes, from which different words can be constructed by concatenation. In the recognition process, speech enters a microphone and is processed electronically to extract and digitize its phonemes. The phonemes are then used to address the computer's main memory, which stores the actions to be taken by the computer. Typically a sequence of phonemes representing a command word is used to evoke execution of a specific program. To synthesize speech, phonemes are retrieved under program control from the computer's memory and, after suitable processing, are fed into a loudspeaker.

Using a small number of phonemes, a large number of different words can be formed. However, minor differences in tone or pronunciation can lead to errors; the error rate tends to increase rapidly with the number of words that must be recognized. Computer understanding of spoken sentences is impractical with our present understanding of natural language processing - this issue is examined further in Sec. 4.

The state-of-the-art of voice recognition is represented by the Speechlab voice recognition unit available as an option for PCs such as the Apple II. This device enables the PC to recognize up to 32 user-selected words.

However, speech recognition, as opposed to synthesis, is quite difficult technically. The limited vocabularies of contemporary voice recognition units can be expanded to some extent by increasing memory size. Even with this expansion, voice recognition units are quite "stupid." They must be "retrained" to recognize each new voice. They are incapable of distinguishing between homonyms on the basis of context, and are confused by slurs, clisions, accents and other distortions of basic speech. In short, a great deal of development needs to occur before voice recognition units replace keyboards as the primary human-computer interface. Speech synthesizers, on the other hand, are available from many sources; and most of the speech processing electronics can be placed on a single LSI chip. The vocabulary of a speech synthesizer is limited mainly by the available memory space. Speech synthesizers have been incorporated into such devices as calculators for the blind. The quality of the synthesized speech is inferior to that of human speech, but is no more difficult to understand.

Forecast: Steady improvement [illegible] vocabulary and speech quality is expected as increases in IC component density allow larger memories and more sophisticated speech-processing circuitry in voice I/O devices. Voice input to PCs is likely to be limited to short commands used to control preexisting programs. The creation of new programs directly from speech input is not seen as feasible during the next decade. Voice output devices for PCs should achieve speech quality comparable to human speech, with no significant limitations on vocabulary size and type. This development is expected to increase greatly the use of PCs in such areas as teaching reading and spelling to young children, and teaching foreign languages. voice communication should also greatly improve the quality and range of PC-based games.

Visual image communication: While PCs obviously can be used to generate an unlimited number of images on a video display, these images can also be used to convey input information to the computer. This requires a computer program that generates a set of images, and a means by which a user can select one of the displayed images. A light pen is a well-known way of doing this. It contains a photodetector which when held close to the desired image on a CRT screen generates a signal to the computer. From this signal the computer can determine the position of the light pen relative to the screen, and hence the particular image being pointed to. A light pen used in conjunction with a keyboard allows complex ideas to be conveyed to the computer very quickly. With appropriate graphics software the light pen can be used to manipulate visual images in various ways to create new images. Such techniques have been used extensively in engineering design for many years. The main costs of these systems are in the software required, and the memory space and processing speed needed to support the software. We expect, however, that these costs will decline to the point where video input techniques of this kind are economical in PCs. It is also technically possible to replace the light pen by the user's finger, so that by pointing to an object on the screen, the user's wishes can be conveyed to the computer.

Special I/O devices: Most of the I/O devices discussed so far are designed for interfacing human beings with PCs. Many potential applications of PCs require efficient means for interfacing the PC with specific devices such as:

1. Kitchen appliances;
2. Security devices like burglar alarms;
3. Heating and cooling systems; and
4. Telephone sets.

Most of these devices require sensors that can convert physical quantities such as temperature, pressure, fluid level, etc. into electrical form. Further preprocessing including analog-to-digital conversion is normally needed before the sensor information can be processed by the computer. Current prices for conversion devices are in the order of $100 per sensor, far too expensive for all but the most dedicated enthusiasts.

Forecast: It is anticipated that wide variety of very low-cost sensors suitable for PCs will become available in the 1980's. These sensors are likely to be the result of current research to develop electronic sensors for use in automobiles in the effort to increase fuel economy and reduce exhaust emissions. It appears that most of the necessary sensors including their support circuitry like analog-to-digital converters, can be manufactured as integrated circuits. This should not only make them inexpensive, but should also make them very easy to connect to PCs.

Adequate control of most household appliances is achievable by switching on or off its AC power line. By placing a simple computer-controlled switch in the power line, and by equipping the appliance in question with appropriate sensors, essentially complete control of the appliance can be assigned to the PC. Interestingly, no special connections are required between the appliance and the PC; they can communicate via high-frequency coded signals transmitted through the existing wiring in a building. (This technique has long been used for "wireless" intercoms.) [A possible side effect of this application is interference among PCs operating appliances in homes or offices.] As energy costs increase in the 1980's, it is expected that PCs will be used extensively in this manner to monitor and control energy consumption.

4. SOFTWARE

4.1 Introduction

The needs of different users of a computer are accommodated by means of software, a term that embraces all the programs used in a computer, and the languages used to write the programs. The program types of interest in the PC context are as follows:

1. Applications programs;
2. System control programs; and
3. Language-processing programs.

Some PC user's, primarily hobbyists, write much of their own software. Others, including small business users, require "turnkey" systems in which all the software is supplied and maintained by the PC manufacturer or an independent software house. A substantial industry exists that sells software to users of all types of computers. It is expected that as the PC market expands, the demand for prepackaged software will greatly increase. This seems to be a necessary condition if the market is to expand to include the general public, that is, with PCs as consumer electronic products.

As discussed in Sec. 1, most computer programming is done using either CPU-specific assembly languages, or else machine-independent high-level programming languages. A recent survey of programming language usage indicates little change over the past 25 years (Philippakis, 1977). The most widely used programming language for administrative data processing is COBOL, with assembly languages in second place. Of the languages used to program large computers, BASIC is by far the most popular among PC programmers. Other high-level languages such as PASCAL also have a growing following among PC owners. In addition, some high-level languages such as FORTH have been developed specifically for small computers.

Although programming languages such as BASIC are designed to be easy to learn, they may be too difficult for many PC users with limited technical education. For such naive users, simpler means of instructing a computer are needed and, as discussed in the following sections, are achievable by question-and-answer or "menu" programming methods. Little attention has been given to the needs of such users in the past, hence no "naive" programming languages or standards yet exist.

4.2 Programming Languages

The popularity of programming languages is mainly determined by the extent to which they are used by the suppliers of hardware and software. BASIC has clearly established a firm niche for itself in the PC field, as have the assembly languages for the most popular microprocessors (the 8080, 6800 and 6500 families). A newer high-level language, PASCAL, has been gaining considerable support recently for programming PCs (Helmers, 1977).

Memory size adds substantially to the cost of a PC. As a result some high-level languages have been developed for small computers which are designed to use very small amounts of memory space. These languages are of two types:

1. Simplified versions of standard high-level languages; and
2. Languages that use very condensed coding to minimize program length.

A representative example of the first approach is Tiny BASIC which uses only 2K bytes of RAM, and is a simplified dialect of standard BASIC (Wang, 1977). A language that minimizes memory space by very dense coding is FORTH (James, 1978). FORTH uses stack-oriented Polish notation, and FORTH programming is done in a recursive style similar to that required for LISP.

It would be very useful if a PC could be programmed in "natural" language (English)in all its subtleties and shades of meaning. However, the complexities of natural languages, in particular, the dependence of meaning on context, are such that programming in unrestricted natural languages will not be achievable for the foreseeable future. Rather than program directly in English, another approach is to design programs that take a user's problem specification written in English, and automatically generate a program to solve the problem. Automatic programming of this kind has been the subject of research for several years; however, the results to date been disappointing (Heidorn, 1976).

The user can exercise substantial control over a PC without knowledge of a formal programming language if he/she has a wide range of prepackaged programs available and if the program selection and data input processes can be conveyed to the computer in English (or the native written language of the user). This can be readily achieved by having the PC (via suitable control programs) present the options available to the user in the form of (multiple-choice) questions. The questions can be designed so that the precise format of the possible answers is included in the question. Thus, the user has to remember very little in order to use the computer. A hypothetical example of a computer-user question-and-answer session follows.

```
(Computer)  WOULD YOU LIKE TO PLAY A GAME?
(User)      YES
(Computer)  SELECT ONE OF THE FOLLOWING BY TYPING
            IN THE CORRESPONDING NUMBER
                1.  BLACKJACK
                2.  CHECKERS
                3.  CHESS
                4.  NIM
                5.  POKER
(User)      5
(Computer)  POKER, HOW NICE!  WOULD YOU LIKE TO
            DEAL?
```

and so on. This type of communication has also been called menu programming because the computer presents a "menu" of available choices to the user.

Forecast: We believe that the percent of PC users who do their own programming will decrease (although the absolute number of user/programmers will increase), and that the majority of PC users will neither have the desire nor the training to program using conventional programming languages. Among the programming languages that will be used, BASIC and assembly languages will probably retain their current lead through the 1980's. The success of other languages such as PASCAL is likely to hinge on the support they obtain from hardware and software manufacturers. The fact that PASCAL is extremely popular in university computer science departments will not alone ensure the survival of PASCAL; the demise of the once-popular ALGOL is a case in point. It is expected that as memory costs decrease, languages such as Tiny BASIC and FORTH will disappear from the PC scene. Languages as compact as FORTH are relatively difficult to learn, which is also a limiting factor in their applicability to PCs. However, PASCAL does seem to be developing the breadth of support to ensure that it will be a serious competitor to BASIC. Other languages well-known to computer proffesionals, such as COBOL, FORTRAN, PL/I, RPG, and LISP are also becoming widely available for the intermediate and larger sized PC's used in business and scientific applications.

Natural language programming and automatic programming still appear to be at the basic research stage. We anticipate that menu programming will be the primary means by which naive users will control PCs in the 1980's. This can be expected to increase the demand for easy-to-use software packages, and the industries supplying this software should prosper accordingly. Increased use of display-oriented "object" programming methods such as Smalltalk is also expected (Kay and Goldberg, 1977).

4.3 Systems Programs

A PC requires certain control programs to enable a user to access the various software facilities available. These control programs may be collectively called systems programs and are often supplied by the PC vendor. The most elementary program of this kind is called a monitor program. A typical monitor for 8080-based PCs is DBUG which provides routines for input/output control, such as loading a user's program from a keyboard into main memory. It also assists in program debugging by allowing the user to start and stop program execution at specified breakpoints. (Titus and Titus, 1977). Monitor programs are invariably machine-specific, and no standards for their structure exist.

Monitors are adequate for small PC systems with limited input/output and storage requiremets. With larger systems it is desirable to have control programs that provide the following facilities:

1. Automatic memory space allocation;
2. File manipulation;
3. Text editing;
4. Debugging routines; and
5. Language translators.

Control programs with most of these features are often called operating systems, and were developed for larger computer systems in the 1950's. Operating systems for PCs are available from several sources. Because of their size and complexity, PC operating systems are usually suitable only for PCs with floppy disk secondary storage and relatively large RAM's. Operating systems are primarily of value to a user who employs many different program and data files, especially when some of the files are very big. Operating systems are CPU-specific. An example of an operating system for 8080-or Z80-based PCs is CP/M (Digital Research, 1978).

A particularly useful function of an operating system is the creation of virtual memory by automatically transferring portions of programs between main and secondary memory. This permits execution of a program that is too large to fit all at once in the available RAM space; the operating system automatically transfers the parts of programs currently needed by the CPU to the main memory. Thus, the main (e.g., RAM or ROM) and secondary memory (e.g., tape or disk) are seen by the user as a single very large memory, and the user need not be concerned with the problems of memory space management.

The file-handling features of an operating system allow a user to create, delete, name, merge, copy and move files in various ways. They also allow the user to interface in an easy way with systems programs such as text editors and assemblers. The following sequence of commands to a hypothetical operating system are typical of a work session with a PC:

```
START
CREATE X
(Enter assembly language program)
ASSEMBLE X
LINK X
GO
```

START transfers control of the computer to the operating system. CREATE X informs the operating system that a file to be named X will be entered, say, from a keyboard; in this case X is an assembly language program. The next three commands cause the operating system to translate the program X into executable form, link it with standard subroutines (which may be stored in a "library" file), load it into main memory and have it executed.

Language translators are of two main types, compilers and interpreters. A compiler translates a user's source program to machine-executable form in one step; the resulting object program (in machine language - 0's and 1's) is then executed. (In the case of assembly language source programs, the term assembler is used rather than compiler.) An interpreter, on the other hand, does not create a total object program as such. Each source program statement is translated and executed as it is encountered by the interpreter. Since an interpreter may repeatedly translate the same statement (if it occurs in a program loop, for example) program execution via interpreters is slower. Interpreters are usually simpler and require less RAM space than compilers; for this reason interpreters are widely used in PCs, whereas compilers are preferred in large computer systems.

Forecast: Current systems programs for PCs are primitive compared to those of large computers, primarily because of RAM space limitations. As the cost of RAM storage continues to fall, it is anticipated that the features of well-designed large operating systems, for example, Bell Laboratories' UNIX system, , or its direct descendants, will appear in many PCs [versions of it began to appear in 1979]. The widespread use of monitors and operating systems is hampered by the lack of standards, and the fact that systems programs of this type tend to be tied to specific microprocessors.

Decreases in memory cost can be expected to increase the use of compilers in PCs at the expense of interpreters. It is also expected that language translators and some operating systems routines will be available to an increasing extent in ROM chips, and thus will be more closely integrated with the CPU. This is likely to result in PCs that appear to execute high-level languages directly. An example of this approach is the PASCAL machine introduced by Western Digital Corporation. Computers designed with extensive special processor hardware for the execution of specific high-level programming languages have had little commerical success in the past (Chu, 1975).

5. STANDARDS

The rapidly-increasing number of personal computer products makes the question of compatibility between products one of growing importance. Compatibility requires the existence of standards governing the hardware and software factors that determine compatibility. In the PC area the more important compatibility factors are as follows:

1. Interface buses;
2. Storage media formats; and
3. Programming languages.

Relatively few widely-used standards exist at the present time, and those that do exist are mostly of an ad hoc nature (Isaak, 1978). Standards specification is a recurring problem in the computer industry, hence useful lessons can be learned from past experience.

5.1 Standardization Process

Computer standards fall into two main groups: de facto standards evolving from specific products, and official standards produced by various national and international organizations. In the United States, the organizations most concerned with developing computer standards are the American National Standards Institute (ANSI) and Institute of Electrical and Electronics Engineers (IEEE). The creation of official standards is a slow process, and often its only function is to lend weight to an existing de facto standard. The standards of interest here have no legal force, hence the extent to which they are adopted is determined by market pressures.

De facto standards are established by the most widely-used products. A product often becomes a standard by being the first to reach the marketplace, or by having a manufacturer with a large share of the market. IBM, which holds more than half the worldwide computer market, is the source of many computer standards, such as the FORTRAN programming language, the System/360 computer architecture, and the most widely-used floppy disk storage format. FORTRAN and the System/360 architecture have been standard for about 25 and 15 years, respectively, despite the fact that they have been subject to periodic criticisms and contain many obsolete features. They illustrate well the conservatism of the computer business, and the importance of an established market position. Intel, the leading manufacturer of microprocessors, has had similar influence in the microcomputer area. The widespread use of the S-100 interface can be traced to the MITS Altair computer, the first commercially produced PC.

In a fast-changing area such as the PC market, new products and technologies can render a standard obsolete very quickly. This leads to the abandonment of the standard, or to the production of products at variance with it. Thus, although an ANSI standard for BASIC has been proposed, there is very little compatibility among the versions of BASIC used by different vendors. Otherwise compatible BASIC programs may become incompatible if they are distributed in storage media that use incompatible formats. Although these incompatibilities may be trivial from a technical point of view, they frequently present insurmountable obstacles to the naive computer user. Finally, it should be noted that manufacturers occasionally avoid the use of industry-wide standards in order to reduce the competition their products must face (although in doing so they face the risk that their strategy will backfire, causing potential buyers to avoid their products because of fears of incompatibility).

5.2 Personal Computer Standards

One of the important standards in a PC is set by the interface bus employed. This is usually a function of the microprocessor used, but broadly similar microprocessors can readily be adapted to use compatible interfaces. All peripherals used by a PC must be compatible with its interface bus. Adapters allowing two units with different interfaces to communicate are generally expensive, and they often seriously degrade computer performance. Thus, most PC users will be compelled to use only peripherals that have the same bus standards as their PCs.

As observed earlier, the S-100 bus of the MITS Altair is the de facto bus standard for PCs (at least in terms of the number of designs using it. It is not the standard in terms of numbers of units produced which incorporate it.). The process of establishing an official S-100 standard has recently been initiated by IEEE (Morrow and Fulmer, 1978). However, there are some technical problems with the S-100 bus which limit its reliability, for this reason it has generally been avoided in industrial applications where high reliability is required. It also has the disadvantage of containing far more lines (100) than are needed to control most types of peripherals. Further, the PCs with the highest current production volumes, the Apple II and the

TRS-80, do not use the S-100 bus. Nevertheles, because of its flexibility and the large number of manufacturers supporting it (currently rumored to include IBM), the S-100 bus is expected to be in general use for several years.

Another possible bus standard for PCs is the IEEE 488 bus, also known as GPIB (general purpose interface bus) (IEEE, 1975; Forbes, 1978). Although designed for the control of digital instrumentation, it is used in at least one PC, the Commodore PET. It is widely used in the electronics industry and is supported by a number of powerful IC's that greatly simplify the use of this bus. The larger microcomputer manufacturers have also developed their own bus standards. Intel's MULTBUS is, perhaps, the most widely accepted of these.

The formats used by secondary storage media such as magnetic tapes and floppy disks greatly influence the distribution of software products. Format standards may be more important for the success of the industry than internal bus configurations standards. Tape cassettes are the most popular distribution media at the present time. However, many factors influence tape storage formats including the number of bits stored per inch, the number of tracks used, the block size, the bit encoding technique, etc. Only one informal standard, the so-called Kansas City standard, exists for cassettes, hence cassettes tend to be restricted to use on specific PCs. Floppy disks are less widely used for software distribution than cassettes. The de facto standard format is the IBM 3740 format; however, many other formats are used which aim at increasing disk storage capacity.

No official standards have ever been promulgated for machine or assembly languages. De facto standards exist only to the extent that certain CPU types are more widely used than others. The machine languages used in PCs are those of a small number of microprocessor families, of which the 8080/Z80 family is probably the most important. BASIC is the dominant high-level language. Some use is made in PCs of other established high-level languages, including FORTRAN, COBOL, PL/I and PASCAL. As already noted, there are many incompatible dialects of all these languages. The difficulties of establishing programming language standards are well known (Lee, 1977). Standardization at the monitor or operating system level is negligible, although CP/M appears to be becoming a de facto operating system standard for 8080/Z80 family machines.

Forecast: It is believed that de facto standards will continue to dominate in the PC industry. This is primarily because of the fast rate of technological innovation which rapidly makes old standards obsolete. Also, the computer industry has long tended to follow the standards established by major manufacturers, a tendency that will probably continue. BASIC is expected to remain the most popular programming language, but increasing use will be made of other high-level languages. As PCs increase in power and capacity, the amount of existing software for large machines that they can use will also increase. The S-100 bus will continue to be the standard PC bus for the next two or three years, but its technical deficiencies are expected to lead to its eventual demise. It will probably be superseded by an official standard bus like the IEEE 488, or a widely used industrial bus standard like MULTIBUS. De facto storage media standards are also expected to emerge in the 1980's.

6. NETWORKS

This report does not cover the technological aspects of communications networks. Several references are available for those wishing to look into the technology (e.g., Hiltz and Turoff; Dordick, et.al.; Nilles, et.al. 1976).

Although our definition of the personal computer emphasizes its stand alone capability, its ability to operate unassisted by external computing power, the ability of a personal computer to communicate with other computers can be a major factor in the rate at which the technology is used. Specifically, the interconnection of computers of all sorts and sizes by means of telecommunications networks will constitute a primary influencing factor in development of the post-industrial society. A computer telecommunications network is made up of "an interconnected set of dependent or independent computer systems which communicate with each other in order to share certain resources such as programs or data - and/or for load-sharing and reliability reasons." (Farber, 1972; Dordick, et.al., 1979)

Dordick, et.al. identify five features of computer telecommunications networks that are important to users. They are access, cost, network management, reliability, and compatibility. These characteristics are examined here as they apply to personal computers.

Access

> "In an Information Society, access to information becomes a significant criterion of economic and social participation. It requires information to run a business, manage a household, plan a vacation, earn a degree, or pursue a hobby. To the extent that information sources are located remotely from the user site, they must be either traveled to, transported or accessed via a network of some kind. [Computer telecommunications] Networks provide the channels through which data, the stuff that information is made of, may be made available, transmitted to a user site and stored until needed.
>
> "Networks also provide access to extended computer processing and data storage capabilities. They can reduce the need for proliferation of on-site computer capacity through sharing both memory and applications packages with other users. Whether the network provides access to a single computer or to many, it nevertheless extends the capacity of the user's own facitlities be they a single human brain, a smart terminal or a major computer installation."

The issue of accessibility of computing power has many aspects. In fact, our previous distinction between the personal computer and personal computing refers to the difference between the situation in which the person performing the personal computing is colocated with the computer hardware or merely has access to it by means of a computer terminal, a telecommunications network, and a remotely located computer with time-sharing capabilities. This latter capability is discussed at somewhat more length in Part IV.

To the owner of a personal computer, the ability to communicate with other computers via telecommunications networking can provide an important extension to his/her basic information processing capability. The PC user can swap or acquire software, send and receive messages, play multi-participant games, access large and/or specialized data bases and, in general, perform a variety of functions which would be impossible or impractical to perform with an inexpensive stand-alone system.

Cost

There are two aspects to the cost of computer telecommunications networking: the cost of using the network and the costs saved or foregone as a consequence of that use. The primary medium of the near-term personal computer telecommunications network is the telephone system. Even though telephone technology has improved substantially over the past few decades, the cost of providing local transmission from the terminal to the nearest network port has remained essentially constant. Furthermore, because of the major and growing impact of satellite communications, and optical and microwave transmission over long distances, long-haul communications costs have dropped dramatically over the past ten years. In sum, then, the telecommunications portion of the computer networking cost is expected to remain constant or decrease in the future (unless certain alterations in regulatory policy act to change this trend).

The next major component of cost incurred in computer networking is that of access to specific services provided commercially by means of a network. For the most part, these are large computer time-sharing or data base services of one sort or another. For example, there are more than one hundred computer data bases in existence in the United States today which can be accessed through a computer communications network. The typical data base service charges a "connect" cost of so many dollars per minute or hour of access time and a "hit" cost for each time the search for a specific item of information is successful. A variety of types of data bases are contained within the number available in the United States today, ranging from information on Federally supported technology research projects, to current activities of the U.S. Congress. Furthermore, a new type of consumer oriented data base service has been developed in England under the name of Prestel (also known as Viewdata) and may ultimately be marketed in the United States. This service provides more mundane information, such as lists of the films being shown locally, restaurants serving specific types of food, and the like, but with substantially the same structure of charges as that used for information received from more esoteric data bases.

Computer message systems constitute a major category of the use of computer networks for which a cost may or may not be charged the user. Some "electronic mail" services are available from various of the specialized telecommunications carriers for a transmission and storage fee. Another, hobbyist oriented, electronic message system has sprung up across the country in the last few months. The service is offered at no charge to the user(other than telephone charges) and is called the Community Bulletin Board Service. By mid-1980 more than 150 CBBS and similar services were in operation.

The primary cost saving resulting from the use of computer networking derives form the substitution of electronic transmission of information for the physical transportation of the people containing the same information (telecommuting). Previous research at USC has shown that these cost savings can be substantial, far in excess of the costs incurred in actually performing the networking. (Nilles, *et.al.*, 1976).

The remaining cost to the personal computer owner for computer networking is that of the special hardware and software required to connect the computer to the telephone line or other telecommunications medium. At present the components of this cost item are a modem (an acronym for modulator-demodulator, the device which converts the data string generated and/or received by the computer to a standard form suitable for transmission on the telecommunications link); a device for insuring that the electrical characteristics of the data transmitted are compatible with the telecommunications system (this can either be a data access arrangement - DAA - or the telephone hand-set); and the input-output software required to produce the "handshake" message transfers between the communicating computers. At current prices, the hardware costs for a computer telecommunications capability is in the order of $400 to $300. Simple operating software is generally available free or at a very low cost for the most popular personal computers.

Network Management

Essentially, the management of a computer communications network is the responsibility of the organization providing the network services. Consequently, the user of the services is not generally concerned with network management. However, to the extent that the management of a particular telecommunications network is efficient and innovative, the activities of the network can become more (or less) "transparent" to the user. That is, ideally, the user of a network service should not even be aware that all sorts of complicated transactions, switching from land lines to communications satellites, packaging or coding of the data, etc., are going on in order to transmit the information form place to place. At the state of the present network management technology, there are still too many details of connect and transmission protocol that must be performed by the user for computer networking to be attractive to the general public.

Reliability

Voice communication over the telephone system is relatively insensitive to noise and distortion; that is, although a noisy, distorted connection may be annoying to the users of a telephone, severe interference must occur before the conversation becomes incomprehensible. Unfortunately, when digital data is transmitted over voice grade telephones, the chance of a garbled transmission is much higher than for the case of voice telecommunications. Consequently, the acceptablity of computer communications to frequent users may be reduced in those cases where they must use noisy telecommunications networks.

As telecommunications networks convert to digital transmission techniques, the reliability of data communications will increase substantially. One of the primary techniques for providing this reliability is known as packet switching. In this technique, a data stream is broken up into standard-length packets, to each of which are added digital codes indicating the origin and destination of the packet as well as codes for error checking. Packet switching techniques allow noisy telecommunications links to be bypassed by selecting alternate routes or, if no alternate routes are available, provide for successive re-transmission of individual packets until the data are received correctly. All of these processes are invisible to the user in a well-managed network. Thus, a well-managed, reliable data transmission network essentially provides guaranteed, almost instantaneous message transmission - and confirmation of arrival - to its users.

Compatibility

Ideally, a PC owner wishing to use a telecommunications network should be able to do so at any time and place. In order for this to happen, the network should have the ability to communciate with any type of computer hardware available on the market. This is not typically the case today. Furthermore, various telecommunications networks should be able to interconnect with each other, so that the cost of data transmission between any two points of the earth (or even within the United States) is minimized. This also is not the case today. Although the problems of providing complete compatibility include many issues of regulation, many issues of standards also arise and must be solved before users will have general access to network capabilities.

Forecast

The technological base for network services is already well developed and is growing rapidly, keeping pace with the development of microprocessors. As the size of the market increases, the capability for network interconnection will become a standard part of personal computer design - not "an extra" - in the mid-80s. Although the specific applications technologies will be developed primarily for the business and government sectors - for use in office automation, electronic mail, and related functions - the technology will rapidly become available for home use as well. There appear to be no significant hardware barriers to computer network technology. As mentioned above, the primary issues to be resolved relate to regulation of network service providers and establishment of interconnect standards and protocols. The rate at which these are established will depend on the perceptions of those involved in providing the services, as to the potential size of the computer communications market.

To quote Dordick, et.al.,

> Data network traffic will probably continue to grow at a very rapid rate over the next two decades, perhaps as much as 40% per year as has been estimated by several sources. But even by the end of the century, voice traffic will still constitute the bulk of the network traffic. While data traffic may make up approximately 1% of the total network traffic, it could account for as much as 18% of the revenue. Large investments will be required to enter these [network services providing] businesses but the very high returns, competing favorably with those available in other sectors of the economy, could attract the necessary capital. Indeed, the revenues from the lease, purchase or rental of terminals/computer equipment can be as much as four times that obtained from the delivery or network portion of the entire marketplace.... At the present time, what is not evident is a strong trend toward a universal network available to all economic levels and to the public. The European pattern is not being followed in this country, and, barring any major change in policy, is not likely to be emulated. Instead, there will be continued dependence on market demand; and this demand will initially be felt in the business and government sectors. Small business and consumer access are not likely to be generally available before the end of the century.

Our current analysis tends to modify this position in that we already see evidence of individuals and small businesses taking advantage of or providing some network services. See Part IV for a discussion of network personal computing.

PART III.

PERSONAL COMPUTER USERS AND USES

1. INTRODUCTION

As has been shown in the previous part of this report, the fundamental technology for personal computers is well-advanced. Hardware capabilities are steadily increasing and costs are equally steadily decreasing, driven by other forces than those of the personal computer market. The technology of personal computer software is less well-advanced at the moment and is much more dependent on the nature and size of the personal computer market. Our approach has been to examine this market in two ways: to learn who the present purchasers of PCs are and the uses to which they are putting their computers, and to estimate the potential size of the market over the next ten to fifteen years.

2. PERSONAL COMPUTER QUESTIONNAIRE

2.1 Personal Computer Owners

A questionnaire about personal computers and their uses was distributed to approximately 600 persons in late October and early November, 1978. (A copy of the questionnaire is included as Appendix 1.) Most of the responses were obtained at two computer shows at the Los Angeles Convention Center, one of them devoted to personal computing. Of these, 267 usable returns were obtained from persons who owned or soon expected to purchase a personal computer, and who completely filled out the questionnaire. Some demographic characteristics of the respondents are in Table 3-1.

Table 3-1
Characteristics of Respondents

AGE		LEVEL OF EDUCATION	
Under 20	8.0%	Now attend H.S.	4%
20 - 29	25	H.S. Diploma	2
30 - 44	49	Some College	17
45 - 60	17	A.A. Degree	7
Over 60	1.5	Bachelor's Degree	36
		Master's Degree	25
		Doctorate	11

SEX	
Female	6%
Male	94%

ETHNIC BACKGROUND	
Caucasian	86.0%
Oriental	7
Native Amer.	5
Spanish Surn.	2
Black	0.5

MAJOR EDUCATION FIELD	
Engineering	36%
Business	18
Nat.Hist.-Math	17
Computer Science	13
Health Science	6
Liberal Arts	6
Social Science	3

Of the 267 respondents, 257 already owned or expected to own (actually, 231 did own; 26 expected to own) one or more personal computers. Table 3-2 indicates what personal computer they owned and how many each person owned.

Table 3-2
Computer Ownership

Computer Name*	No.	%
Imsai 8080	45	12%
Exidy Sorcerer	6	2
TRS 80	45	12
Apple II	42	11
Commodore PET	29	8
Altair 8800	17	5
16-Bit CPUs	20	5
Sol	14	4
NorthStar	8	2
Other Z80	33	9
Other 8080	30	8
Other	77	21
Total CPUs*	366	

No. of CPUs Owned*

CPUs/Respondent		%
None	10	4%
1	176	66
2	60	22
3	14	5
4+	7	3

Mean No. CPUs/Respondent: 1.36
Mean No. CPUs/Owner: 1.42

*"Mainframes," actually, consisting of at least a CPU, some memory and an I/O part for a display system (or a self-contained display).

All but 12 of our 267 respondents owned or expected to buy peripheral equipment. Half of them owned or expected to own at least four peripherals. Of the 1290 peripheral devices listed, dates of actual or expected purchase were given for 1,023. Of these, 544, or 53% were already owned, and 47% expected to be bought. Table 3-3 shows the kind of peripheral equipment owned or expected.

Table 3-3
Peripherals Owned or Expected To Be Owned
Number of Respondents

Hardcopy Printer	164	Color Graphics	55
Cassette Tape I-O	149	Analog-Digital Conv.	52
CRT	142	Joystick or Paddle	52
5" Floppy Disk Drive	120	Speech Recognition	35
8" Floppy Disk Drive	85	AC Line Controller	25
Serial Comm. Interface	76	Wand or Pointer	21
Modem	75	Record and Playback Eq.	20
ROM Board	65	Mag Parallel Comm.	3
Parallel Comm. Inter.	59	Environment Sensor	2
TV Link	56	Other	35
		Total	1290

The "owned" vs. "expected" categories differed markedly for CPUs and peripheral devices. Table 3-4 shows, for the equipment for which a past or future purchase date is given, that 80% of the total CPUs listed are already owned, compared with only 53% of the peripherals. Since many respondents owned or expected to own more than one CPU or peripheral device, the data are shown by 1st, 2nd, 3rd, and 4th CPU or peripheral listed. Data on up to four CPUs are listed, since they accounted for more than 99% of the respondents. We needed to analyze 12 peripherals to account for the same percentage. As the table indicates, of the persons listing at least one CPU, 161 had already bought it, and 26 expected to buy it. By contrast, 126 persons listing one or more peripherals showed past purchases, with 74 persons listing expected purchases. Persons listing 3 or more peripheral devices owned less than half of the devices they expected to own.

Table 3-4
Past and Expected Equipment Purchase Dates

Equipment Listed Item No.	Mainframes		Peripherals	
	Own	Expect to Own	Own	Expect to Own
1	231	26	126	74
2	63	18	112	80
3	13	8	85	81
4	4	3	64	73
5	-	-	58	57
6	-	-	31	35
7	-	-	26	24
8	-	-	18	14
9	-	-	11	14
10	-	-	9	9
11	-	-	2	13
12	-	-	1	5
Total	311	55	544	479
Percent	85%	15%	53%	47%

2.2 Uses

Of our 267 respondents, 237 listed a total of 1,313 uses for their personal computers, for an average of about 5 uses per respondent. Table 3-5 shows the uses indicated.

Table 3-5
Personal Computer Uses

USE	NO.	USE	NO.
Video Games	142	Speech Recognition	42
Board Games	116	Inventory	37
Text Editing	114	Speech Generation	35
Letter and Report Pr.	87	Amortization Compute	30
Address Lists	86	Income Tax Prep.	29
Checkbook Record	82	Stock/Bond Analysis	24
File Maintenance	78	Recipe Storage	24
Graphics Production	69	Simulation	23
Budgeting	61	Household Appl. Cont.	20
Music Generation	49	Sales Records	18
General Ledger	47	Test Administration	13
Teaching Machine	44	Other	43

2.3 Languages

Table 3-6 shows the most frequently listed programming languages. The "Other" category included ALGOL, FOCAL, FACETOT, RPG, and RTL, and other languages which were listed by 15 or fewer respondents.

Table 3-6
Programming Languages Used

LANGUAGE	NO.	LANGUAGE	NO.
BASIC	229	APL	65
Assembly	184	PASCAL	56
FORTRAN	179	PL-1	39
COBOL	85	Other	119

2.4 CPU Memories

Our respondents' personal computers generally had fairly large main memories. The median CPU memory of the 211 who answered this question was 25-32K bytes. Unlike the area of peripherals, where almost everyone expected to obtain more, only half of our respondents indicated any expectation of main memory expansion. The 136 responding that they expected to buy memory showed a median expected size of 33-48K. Since the majority of our respondents own or expect to own floppy disk drives, they may not feel larger CPU memory is needed. Table 3-7 shows present and expected memory capacity.

Table 3-7
CPU Memory Owned and Expected
Number of Respondents

SIZE	NOW OWN	EXPECT TO OWN
0-1 K	5	1
2-4 K	12	2
5-8 K	20	10
9-16K	31	9
17-24K	14	6
25-32K	41	30
33-48K	35	30
49-65K	41	41
66K +	12	7
Total	211	136
No Response	56	131

2.5 Network Access

Very few of the personal computer users in the survey have network access to other computers. Only 37 of them indicated that they had such access, and these indicated only one to three uses each. Unfortunately, our questionnaire did not ask how many users would like to have network access. Note that the number of users confirming access is only half the number of modems reported in Table 3-3.

On the other hand, it is clear from the interest in PC hobbyist networks such as PCNET that the uses of formal and informal communication networks will increase.

2.6 Sources of Training and Information

Although many PC owners have received formal training in programming, a large number of them are self-trained. Table 3-8 shows the breakdown.

Table 3-8
Sources of Computer Training

SOURCE	NO.
Self	71
Undergraduate College	66
Graduate College	56
On the Job	50
High School	13
Military Service	4

Almost half of the respondents reported reading four different personal computer-oriented magazines, as indicated in Table 3-9.

Table 3-9
Computer Magazines Read

MAGAZINE	NO.	MAGAZINE	NO.
Byte	185	Datamation	73
Kilobaud	137	Mini-Micro Sys.	52
Interface Age	121	People's Comp. Company	32
Creative Computing	98	On Line	19
Interface	79	Comp. Music J.	11
Dr. Dobb's J.	74	Comp. Hobbyist	4

Total 991
Mean 3.7

2.7 Other Electronics Owned

Personal computers appear to be just one of many electronic devices that their owners have. They reported owning 271 television sets, 559 radios, and 539 other electronic devices, for a total of 1,369 devices.

Table 3-10
Electronic Devices Owned

DEVICE	NO.	NO. OF TVs	NO.
4-Function Calculator	174	1	41
Programmable Calc.	111	2	54
Stereo Music	92	3	22
Video Games	75	4	9
CB Radio	40	5+	4
Videotape Recorder	27		
Ham Radio	20	NO. OF RADIOS	NO.
		1	38
		2	30
		3	29
		4	26
		5+	54

2.8 Investment in Personal Computer Equipment

We were able to obtain investment information from 261 of our respondents. The amounts of their original and subsequent investments are shown in Table 3-11.

Table 3-11
Original and Subsequent Investment
Number of Respondents by Percentage

AMOUNT	ORIGINAL INVESTMENT		SUBSEQUENT INVESTMENT	
None	28	11%	103	39%
Under $1000	93	35	51	19
$1000 to $1999	51	19	32	12
$2000 to $4999	52	20	36	14
$5000 to $9999	21	8	20	8
$10000 and over	16	6	17	6

We assumed that the older personal computer models (e.g., the Altair 8800) would be associated with a fairly high subsequent investment compared to the original investment, and that the opposite would be found for the newer machines (e.g., TRS-80, Apple II). Table 3-12 shows that the data support that assumption, and gives additional details.

Table 3-12
Average Investment by CPU

COMPUTER	ORIG. INVEST.	SUBSEQ. INVEST.	TOTAL
IMSAI 8080	$3212	$3804	$7016
TRS 80	1756	987	2734
APPLE II	2280	1013	3293
PET	1929	1107	3036
Altair 8800	2933	4875	7808
16-Bit CPUs	6700	4975	11675
SOL	4107	5286	9393
NorthStar	2625	3438	6063
Other Z80	3818	2182	6000
Other	2108	2257	4365

Table 3-13 shows the expected finding that investment is correlated with age of the owner except for those over 60. Table 3-14 also shows the surprising finding that investment is not correlated with level of education except in differentiating between those with an associate of arts degree and those who are still in high school from all the others.

Table 3-13
Average Investment by Age and Level of Education

AGE	ORIG. INVEST.	SUBSEQ. INVEST.	TOTAL
Under 20	$1737	$2079	$3816
20 to 29	1795	2507	4302
30 to 44	2726	1942	4668
45 to 60	2583	2571	5154
Over 60	2500	500	3000

Table 3-14
Average Investment by Level of Education

LEVEL OF EDUC.	ORIG. INVEST.	SUBSEQ. INVEST.	TOTAL
Now in H.S.	$1063	$1375	$2438
H. S. Diploma	3013	2250	5263
Some College	2782	3231	6013
A. A. Degree	1092	750	1842
Bachelor's Degree	2552	2156	4708
Master's Degree	2547	1971	4518
Doctorate	1775	1975	3750

2.9 Organizational Memberships

We asked our respondents about organizational membership, listing 22 organizations to which they might belong (including "Other"). Only half belonged to any computer-related organization and only 15% belonged to two or more. Combining this with data presented earlier in this report, we may characterize our respondents as people who have many pieces of computing equipment, use it in many different ways, but do not join organizations to talk about it. Sixty-two respondents said they belonged to the California Math Council and twenty-eight to other organizations.

2.10 Other Computer Usage

In response to a question about using computers at work, 80% said they used computers on the job, 84% said their subordinates used them, and 81% said they used computer outputs at work. Thus, we may add to our characterization the generalization that they fit the "spillover" theory of recreation, which says that people carry into their leisure hours some of the activities in which they engage during working hours.

2.11 Sources of Funding for Personal Computers

Not only do most personal computer users also use computers at work, but the principal outside source of funds for personal computer users is employers. Thirty-one people said some of the funds came from employers, compared with only 10 listing personal gifts as a source, 5 listing school, 4 a combination of sources, and 27 a source other than those. What kind of people receive external funding for their personal computers? Table 3-14 shows the relationships between funding, education, and age.

Table 3-15
External Funding Percent by Education and Age

EDUCATION LEVEL	EXTERNAL FUNDS PERCENT					
	None	0-20%	21-40%	41-60%	61-80%	81-100%
In High School	3	1	1	-	-	1
H.S. Diploma	4	-	-	-	-	-
Some College	25	-	-	2	1	7
A.A. Degree	14	1	-	-	-	-
Bachelor's Degree	55	5	1	4	-	9
Master's Degree	36	4	2	2	4	6
Doctorate	14	1	1	2	-	6
AGE						
Under 20	7	1	1	1	-	5
20 to 29	38	6	1	1	-	5
30 to 44	81	5	3	6	1	16
45 to 60	29	1	-	1	4	3
Over 60	2	-	-	-	-	-

We see, in Table 3-15, above, that most people do not obtain outside funding; but, of those who do, about half get 81 to 100 percent. Furthermore, while the younger people might need more outside funds, the older and better-educated are more able to obtain them. Table 3-16 shows other factors related to level of education of our respondents.

Table 3-16
LEVEL OF EDUCATION

MAJOR FIELD	In H.S.	H.S. Dipl.	Some Coll.	A.A. Degree	Bach. Degree	Mast. Degree	Doc. Degree	
Business	-	2	4	6	14	15	2	
Computer	3	-	9	2	7	7	-	
Engineering	2	-	16	7	36	22	3	
Health Science	-	-	-	-	1	1	12	
Liberal Arts	-	-	4	-	10	3	-	
Nat.Sci.-Math	2	-	5	2	15	10	6	
Social Science	-	-	1	1	3	1	4	
INCOME								
Under $10000	8	1	9	1	4	3	-	
$10K to $19999	-	1	14	12	24	7	4	
$20K to $29999	-	1	12	6	35	71	10	
$30K to $50K	-	1	7	-	17	23	9	
Above $50K	-	-	2	-	4	1	5	
TAX DEDUCTIBLE								
All	-	1	9	5	21	11	9	29%
Some	-	2	10	2	14	10	7	24%
None	6	1	17	6	30	26	4	47%
AGE								
Under 20	9	1	7	-	2	-	-	
20 to 29	-	2	8	12	30	12	1	
30 to 45	-	-	21	6	41	37	21	
45 to 60	-	1	7	1	12	15	6	
Over 60	-	-	1	-	2	1	-	

2.12 Relationships with Personal Computing Investment

Do personal computer users with an initial low investment tend to make higher investments later or are their later investments also low? Do people making a high initial investment purchase most of what they need at that time and thus spend small amounts later? Table 3-17 shows that there is a fairly high correlation (the contingency coefficient is + .73) between original and subsequent investment for personal computing equipment.

Table 3-17
Original Investment vs. Subsequent Investment

	SUBSEQUENT INVESTMENT						
ORIGINAL INVESTMENT	None	Under $1000	$1000-1999	$2000-4999	$5000-9999	$10000 & Over	TOTAL
None	27	-	-	-	-	-	27
Under $1000	33	31	13	10	5	27	93
$1000-1999	15	10	13	7	4	2	51
$2000-4999	17	7	5	12	6	4	51
$5000-10000	7	2	1	7	2	2	21
$10000 & Over	7	1	-	-	1	7	16
TOTAL	106	51	32	36	18	16	259

It seems reasonable to assume that the more external funds that were available to personal computer buyers, the larger their purchases would be. The data presented in Table 3-18 show the assumption to be correct. The correlation between external funds percent and original investment is .65, and between external funds percent and subsequent investment is .51.

Table 3-18
External Funds Percent by Original and Subsequent Investment

	ORIGINAL INVESTMENT					
EXT. FUNDS	Under $1000	$1000-1999	$2000-4999	$5000-9999	$10000 & Over	TOTAL
None	68	31	36	12	7	154
1 %-20%	6	3	1	2	-	12
21%-40%	1	1	2	1	-	5
41%-60%	2	2	2	2	1	9
61%-80%	-	-	2	2	-	4
81%-100%	9	6	4	2	-	28
TOTAL	86	43	47	21	15	212
	SUBSEQUENT INVESTMENT					
None	36	24	24	17	9	110
1 %-20%	4	2	3	-	-	9
21%-40%	1	-	-	-	1	2
41%-60%	2	2	2	-	-	6
61%-80%	-	-	1	1	1	3
81%-100%	5	3	2	1	4	15
TOTAL	48	31	32	19	15	145

Is there a relationship between size of investment and taking a tax deduction on it? Table 3-19 shows a fairly high relationship between tax deduction and both original and subsequent investment. The correlation between tax deduction and original investment is .64 and between tax deduction and subsequent investment is .53.

TABLE 3-19
Number Reporting Taking Tax Deduction by Size of Investment

INVESTMENT	ORIGINAL			SUBSEQUENT		
	None	Some	All	None	Some	All
Under $1000	44	9	23	26	5	16
$1000-1999	20	16	7	11	9	7
$2000-4999	22	12	9	21	9	8
$5000-9999	4	7	10	1	7	9
$10000 & Over	2	2	8	3	4	7
TOTAL	92	46	47	52	34	47
AVG. INVESTMENT	$1880	$3087	$3930	$2067	$4279	$4202

Those taking a tax deduction on some or all of their personal computing investment spend about twice as much as those who do not.

In what ways is annual income of personal computer users related to their investment behavior, sources of funds for computing equipment, use of tax deductions on purchases, and whether they use computers on the job? Table 3-20 shows a strong, predictable relationship between annual income and the characteristics mentioned.

TABLE 3-20
Characteristics Related to Annual Income

	ANNUAL INCOME					
	Under $10K	$10K-19K	$20K-29K	$30K-50K	Over 50K	TOTAL
ORIGINAL INVESTMENT						
None	5	4	9	6	3	27
Under $1000	11	24	31	21	2	89
$2000-4999	2	8	24	12	4	50
$5000-9999	-	3	11	6	1	21
$10000 & Over	1	2	8	2	2	15
TOTAL	27	61	96	56	13	253
Avg. Original Investment	$1333	$1861	$3016	$2321	$3615	$2435
SUBSEQUENT INVESTMENT						
None	15	18	40	21	4	98
Under $1000	7	13	18	11	2	51
$1000-1999	2	8	10	11	-	31
$2000-4999	1	11	15	5	3	35
$5000-9999	1	7	8	3	1	20
$10000 & Over	1	4	5	3	3	16
TOTAL	27	61	96	54	13	251
Avg. Subsq. Investment	$1093	$2525	$1995	$1796	$4231	$2100
Avg. Total Investment	$2426	$4386	$5011	$4117	$7846	$4535
EXTERNAL FUNDS						
None	12	39	57	39	8	155
1 %-20%	3	3	6	1	-	13
21%-40%	1	1	2	1	-	5
41%-60%	1	1	5	3	-	10
61%-80%	-	2	2	-	1	10
81%-100%	4	10	8	4	1	27
TOTAL	21	56	80	48	10	215
TAX DEDUCTION REPORTED						
All of Investment	2	14	17	20	3	56
Some of Investment	2	10	18	11	6	47
None	18	25	39	9	-	91
TOTAL	22	49	74	40	9	194
USE COMPUTER ON JOB						
Yes	70%	77%	86%	75%	86%	80%
No	30%	23%	14%	25%	14%	20%

The correlation between annual income and original investment is .37, indicating that only about 10% of the variation in investment is attributable to income differences. The correlation of annual income with subsequent investment is .35, with similar predictive power. The correlations of annual income with percent of external funds used is .47, and with tax deduction reported is .46, thus about 20% of the variation of those variables is related to annual income. The correlation between income and use of computers on the job is .37. The highest use category are those earning from $20,000 to $50,000 per year.

Table 3-21
Characteristics Related to Educational Field

	EDUCATIONAL FIELD							
	Bus. Adm.	Comp. Sci.	Eng.	Health Sci.	Lib. Arts	NatSci Math	Soc. Sci.	TOTAL
ORIGINAL INVESTMENT								
None	6	3	6	2	2	6	1	26
Under $1000	15	12	37	3	7	13	1	88
$1000-1999	2	5	22	1	4	9	4	47
$2000-4999	11	5	15	7	2	8	1	49
$5000-9999	5	4	6	-	2	2	1	19
$10000 & Over	3	1	4	-	2	2	1	13
TOTAL	42	30	90	13	19	39	9	242
Avg. Investment	$2750	$3617	$2128	$1846	$2921	$1962	$3278	$2341
SUBSEQUENT INVESTMENT								
None	16	6	34	6	10	19	2	93
Under $1000	9	9	13	2	5	9	1	48
$1000-1999	2	4	16	2	2	2	3	31
$2000-4999	5	8	15	-	-	4	1	33
$5000-9999	6	2	7	1	-	4	-	20
$10000 & Over	4	1	5	-	2	1	2	15
TOTAL	42	30	90	11	19	39	9	240
Avg. Subsq. Investment	$2798	$1033	$2117	$1045	$1605	$1590	$3667	$2113
Avg. Total Investment	$5548	$4650	$4245	$2891	$4526	$3552	$6945	$4454
EXTERNAL FUNDS PERCENT								
	Bus.	CSi.	Eng.	HSi.	Lib.	NSM.	SSi.	TOT
None	26	15	64	8	9	24	4	150
1 %-20%	3	2	7	-	-	-	1	13
21%-40%	-	-	1	1	1	2	-	5
41%-60%	1	3	1	1	1	2	1	10
61%-80%	3	-	-	-	1	-	-	4
81%-100%	2	4	8	3	3	3	2	25
TOTAL	35	24	81	13	15	31	8	207
AVG. %	13%	22%	11%	27%	28%	14%	30%	16%
TAX DEDUCTION REPORTED								
	Bus.	CSi.	Eng.	HSi.	Lib.	NSM.	SSi.	TOT
All	12	7	20	3	5	9	1	57
Some	8	2	17	4	3	6	3	43
None	10	14	34	4	9	14	3	88
TOTAL	30	23	71	11	17	29	7	188
AVG. %	53%	35%	40%	45%	38%	41%	36%	42%

ANNUAL INCOME

	Bus.	Csi.	Eng.	Hsi.	Lib.	Nsm.	Ssi.	TOT
Under $10000	2	8	8	1	2	6	-	27
$10K-19999	10	8	16	1	7	14	5	61
$20K-29999	22	10	38	3	5	10	2	90
$30K-50K	8	3	21	5	2	9	2	50
Over $50000	2	-	4	4	2	1	1	14
TOTAL	44	29	87	14	18	40	10	242
Avg. Income	$26820	18280	27240	42500	26110	23130	28000	26240

EDUCATION LEVEL

	Bus.	CSi.	Eng.	HSi.	Lib.	NSM.	SSi.	TOT
Now in H.S.	-	3	2	-	-	2	-	7
H.S. Diploma	2	-	-	-	-	-	-	2
Some College	4	9	16	-	4	5	1	39
A.A. Degree	6	2	7	-	-	2	1	18
Bachelor's Degree	14	7	36	1	10	15	3	86
Master's Degree	15	7	22	1	3	10	1	59
Doctorate	2	-	3	12	-	6	4	27
TOTAL	43	28	86	14	17	40	10	238

$1000-$1999	20	16	7	11	9	7
$2000-$4999	22	12	9	11	9	8
$5000-$9999	4	7	10	1	7	9
$10000 & Over	2	2	8	3	4	7

The data in the first part of Table 3-21 indicate significant differences in both original and subsequent investment by educational field. The largest original investments were made by computer scientists and social scientists, suggesting that they are buying larger or more complete personal computers. At the low end were health science and natural science-math. On subsequent investment, the social scientists outspent all other groups by $900 to $2600, with business people also well above the others. Health scientists stayed low and computer scientists were also low, again suggesting they bought what they needed in the original purchase. On overall spending, the social scientists led by $1400 to $4000 with business in second place. Overall, the health scientists and natural science-math people spent least. In any case, the average PC owner had already invested almost $4,500.

Who received outside funding for personal computers? Those getting the most outside funding are social scientists (a fact which may explain their large purchases), liberal arts and health science people. Engineers receive the least outside funding, and, surprisingly, business-trained people are next to the bottom of of this list. Evidently, the engineers and business people are buying their personal computers for combined work and personal use, and have no one to look to for financial assistance. On taking tax deductions, the business people are from 8% to 18% ahead of all other groups, further suggesting business use of their personal computers.

On annual income of our respondents, only two groups stand out from the rest. Health sciences people reported incomes averaging $16,000 larger than the average of all groups and computer scientists reported their income about $8000 below the average, probably because of the young average age of people in that profession. The highest levels of education, as expected, are among the various science groups and engineers. However, more than one-third of the business people reporting also had graduate degrees. Evidently, the business people using computers are those with the most education, not surprising since advanced business education generally includes use of computers and use of concepts and models encouraging computer use. An inference that can be drawn from this data is that the large number of bachelor's and master's of business administration degrees granted by colleges and universities is creating a market for personal computers.

3. SURVEY ANALYSIS

What kinds of statements and inferences can be made from this kind of questonnaire data? First, we cannot assume that the sample of personal computer users responding to our questionnaire are representative of Americans, southern Californians, or even of personal computer users. In fact, as will be seen later, we are reasonably sure that those answering the questionnaire are not even typical of the average new PC buyer in early 1979. Therefore, although we describe our respondents in typical demographic terms, it is not clear from the questionnaire alone that any other personal computer user group would have similar characteristics. We have reported it so that the readers can make their own inferences about the data. The data on age, sex, education, income, and field of study help the reader understand our data. The information on equipment owned, languages, uses, other electronic devices, etc. is mostly hypothesis generating, suggesting additional analyses or data collection processes to test hypotheses suggested by our findings.

The crossbreak information, beginning with Table 3-12, provides more hypotheses for further study, but also provides information that has present value. It is not surprising, for example, to learn that people spent more money on their subsequent investments than on their original investment, as did people who owned "other" CPUs, about half of which were "homebrew" machines. They had both the time and money to enhance their original equipment. By contrast, the buyers of PETs, Apple IIs, and 16-Bit machines have not yet had time to add as much to their original equipment. We also believe that there is some validity to the finding that the younger respondents tended to spend more on subsequent than on original investments, while the opposite is true of older users. It was the young users who first entered the personal computer market. Their initial funds were relatively limited, but they have had the time, and presumably the money, to spend on replacing the original equipment or adding peripheral equipment to it. The older persons, entering later, may eventually spend more than the younger ones, but they entered relatively late and have had less time than money for subsequent investments.

We were surprised to find that people having "some college" had the largest average investment in personal computing and that those who have high school diplomas, but no further education, had the next largest investment. Probably they entered the market early as compared with people who were getting degrees. This speculation is further supported by the negative correlation between investment and years required to obtain the degree held. We found what we expected to find on relationship of income to amounts invested — generally, the larger the income, the more money invested, but the relationship is fairly flat in the middle of the income range. Only "Under $10,000" and "Over $50,000" groups were really different from the midrange groups in amounts invested. Generally, those with the largest incomes spent a higher proportion of their own money than did those in lower income brackets. The higher the income, the more likely they were to take a tax deduction on equipment purchased. This is probably due to combination of causes. First, the higher the income, the more likely the persons are to be able to take advantage of tax deductions and to be accustomed to taking them. Further, the higer income people are more likely to be using their computers on their jobs or in their own businesses, thus making the tax deductions justifiable.

Studying the relationships to educational field is also interesting. We found that the big spenders were in social sciences or business. Those spending the least were in the health sciences group, whose reported incomes were $16,000 above the average for the other groups. The social science, liberal arts, and health science people had the highest percent of external funds used, while the people in engineering, business, and natural science and math had the least outside funding. Not surprisingly, the business people had the highest proportion subject to tax deduction.

To return to an earlier point worthy of consideration in the survey material just reported the fact is that, for the most part, the survey respondents were residents of southern California. A question to be answered then is whether the results of the USC survey can be taken to be representative of personal computer owners throughout the United States who have responded to other surveys. That is, are the demographic characteristics of personal computer owners in southern California different from those of other PC owners elsewhere in the US. We can make the hypothesis that the respondents to our survey were typical of survey-responding PC owners throughout the country.

In order to test this hypothesis, we have compared some of the vital statistics of the respondents of the USC survey with those of respondents to surveys recently completed by two personal computer oriented periodicals, Byte and Interface Age magazines, whose editors were kind enough to give us copies of their results. It was not possible to make entirely exact comparisons between the three different sets of data, since the intervals in such factors as age and income, occupational titles, types of educational background, and the like differ slightly from one survey to the other. Nonetheless, as can be seen in Figures 3-1 to 3-6, there is fairly high correspondence between the statistics for each of the characteristics measured in the three different surveys. Consequently, we conclude that the hypothesis was correct and that our survey, as well as the others, are fairly typical of the first group of PC owners, since both magazines conducted their surveys on a national basis.

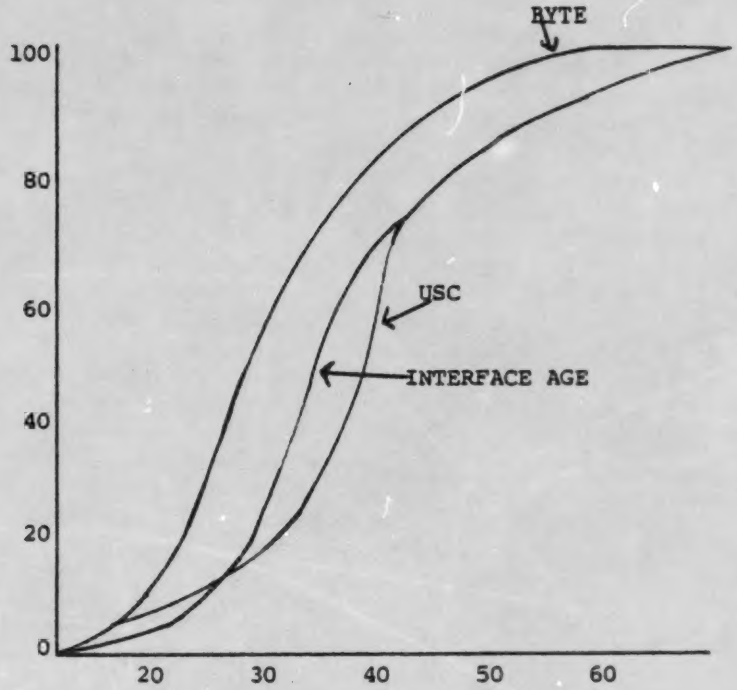
As mentioned earlier, it is important to recognize that the respondents to our survey and to the others mentioned, are undoubtedly not typical of PC owners of the future, or even of the majority of PC owners in 1979. For example, estimates by members of our Advisory Board and by proprietors of computer stores lead us to believe that those who answered our questionnaire represent less than 25% of the contemporary market and, quite possibiliy, may only represent 5% of the market. Thus, the dominant portion of the growth of the use of personal computers in the future depends on the acceptance of personal computers by quite a different set of individuals. The following sections of this report cover the available data and our present conjectures about these future users.

4. MODELING MARKETS FOR TECHNOLOGICAL PRODUCTS

4.1 Introduction

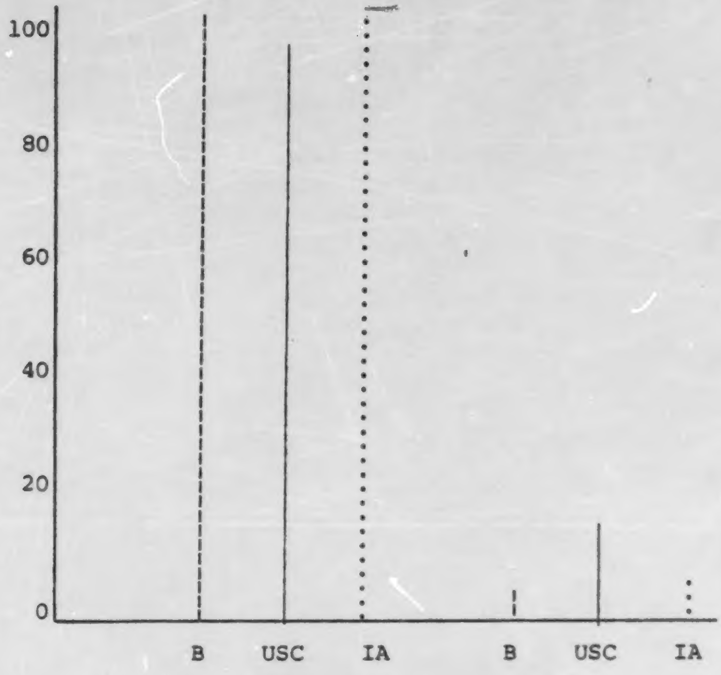
Personal computers can be viewed as a newly introduced, high-ticket consumer product. As such, they can be anticipated to follow the same patterns of sales as other innovations in their class. Detailed studies of the markets for such products have been made over the years and a number of models are available in the literature. The standard paper by Rogers (1962) shows that the life cycle of innovations can be described by an S-shaped cumulative curve and a bell-shaped incremental curve (Figure 3-7). The

FIGURE 3-1



Cumulative Percent - Age Distribution

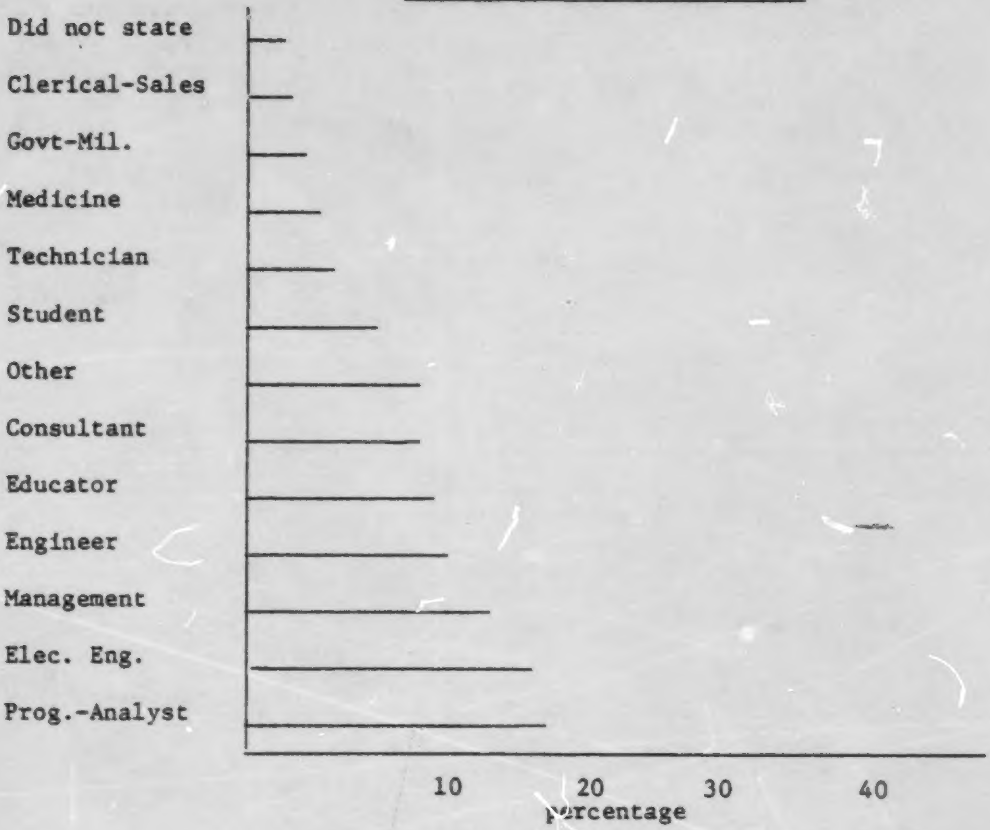
FIGURE 3-2



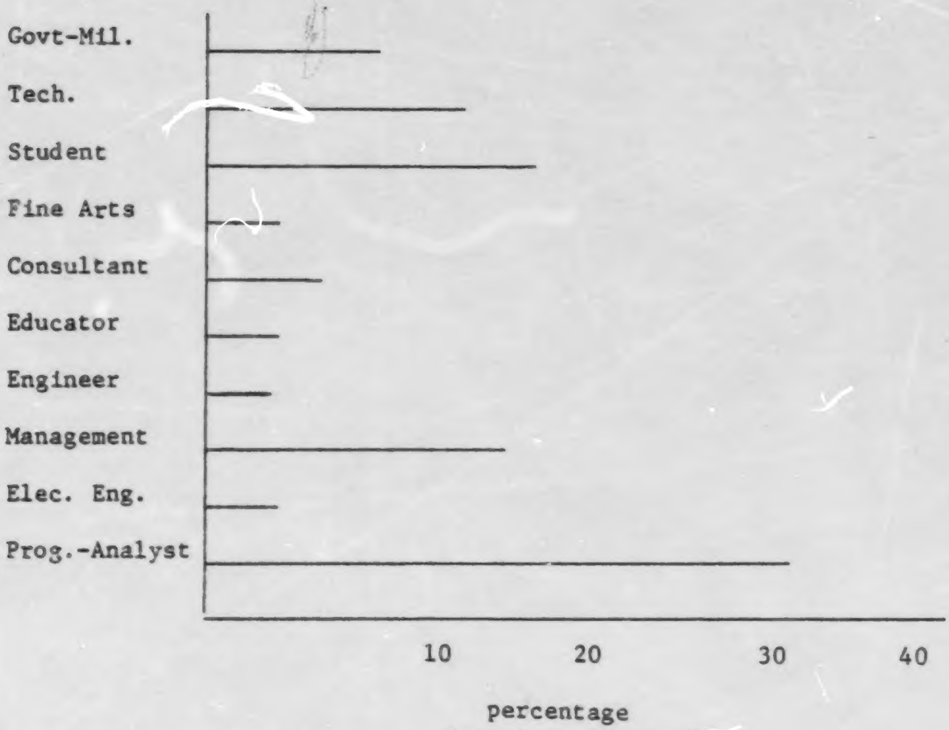
Male Female

FIGURE 3-3

USC SURVEY OCCUPATIONAL DATA



Primary Occupation



Secondary Occupation

FIGURE 3-4

EDUCATION DATA COMPARISONS

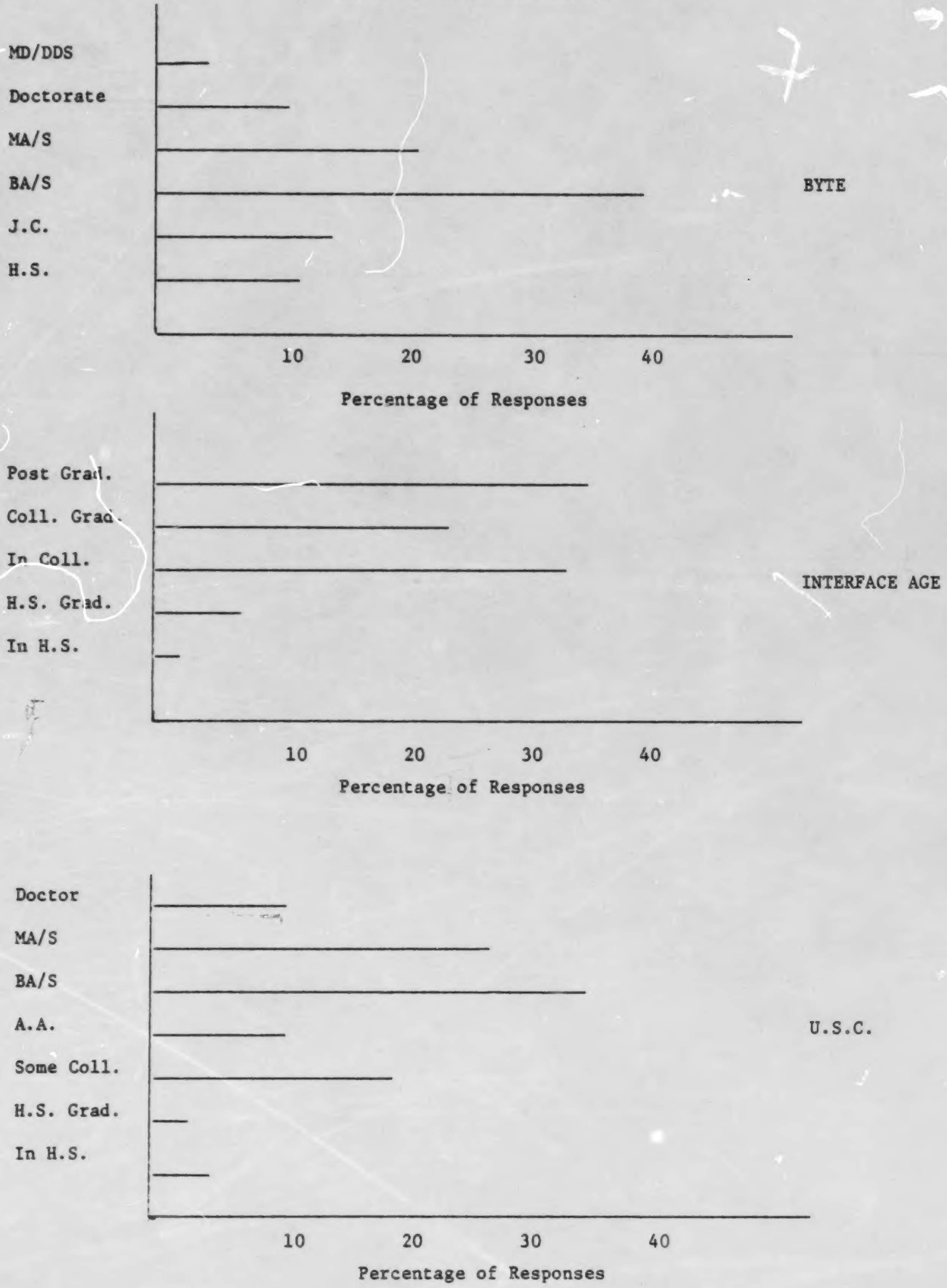


FIGURE 3-5

OCCUPATIONAL DATA COMPARISON

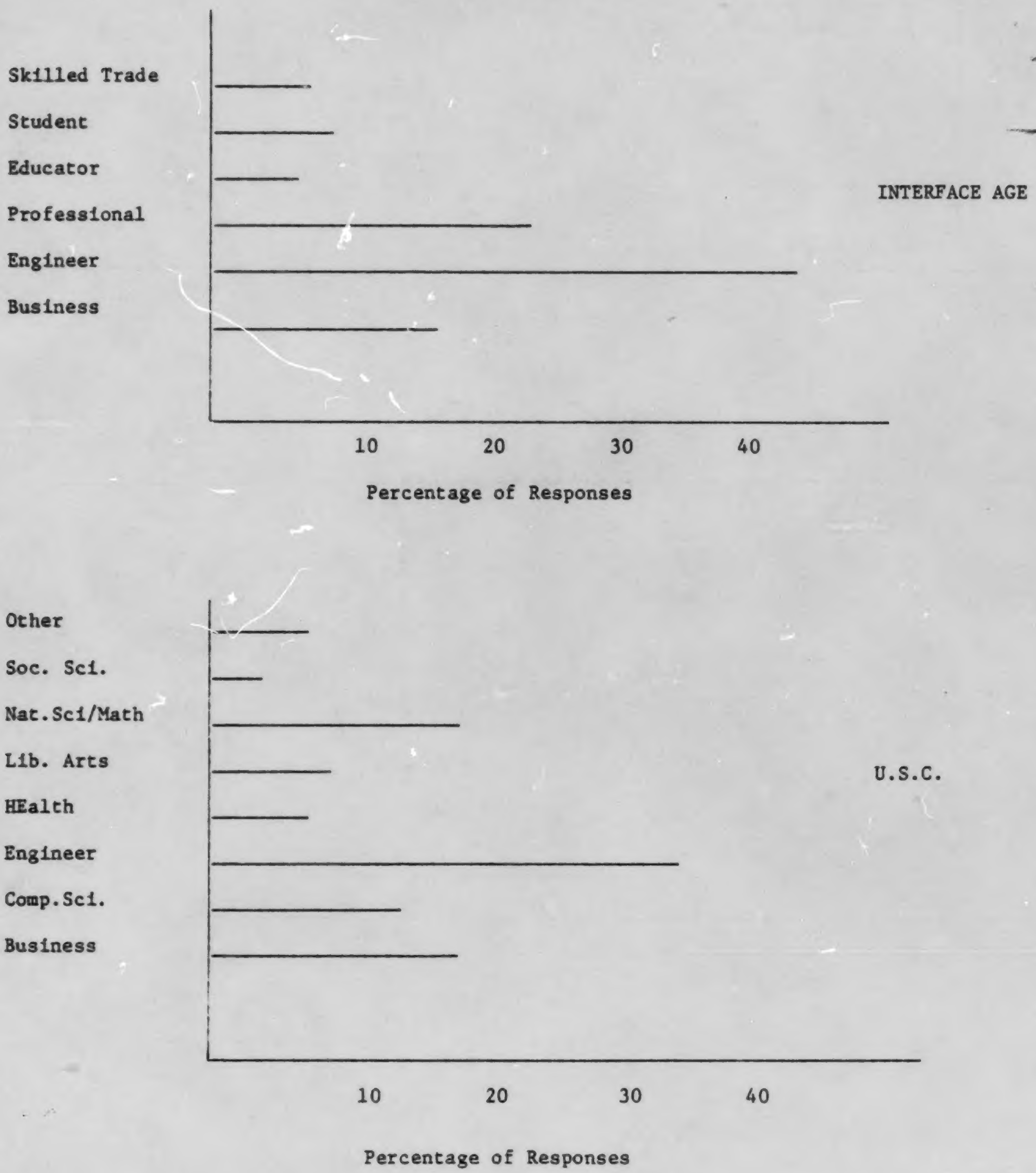
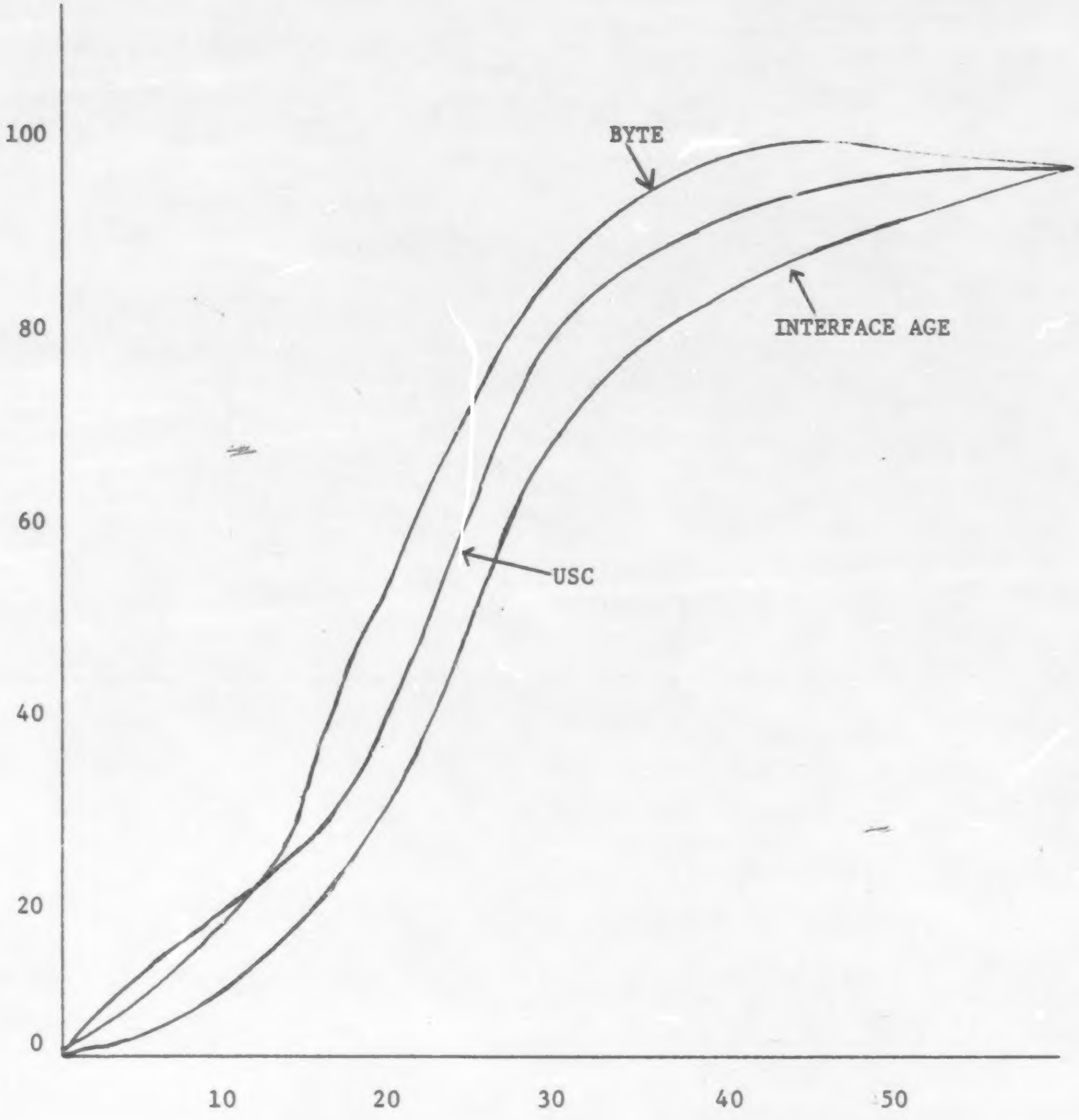
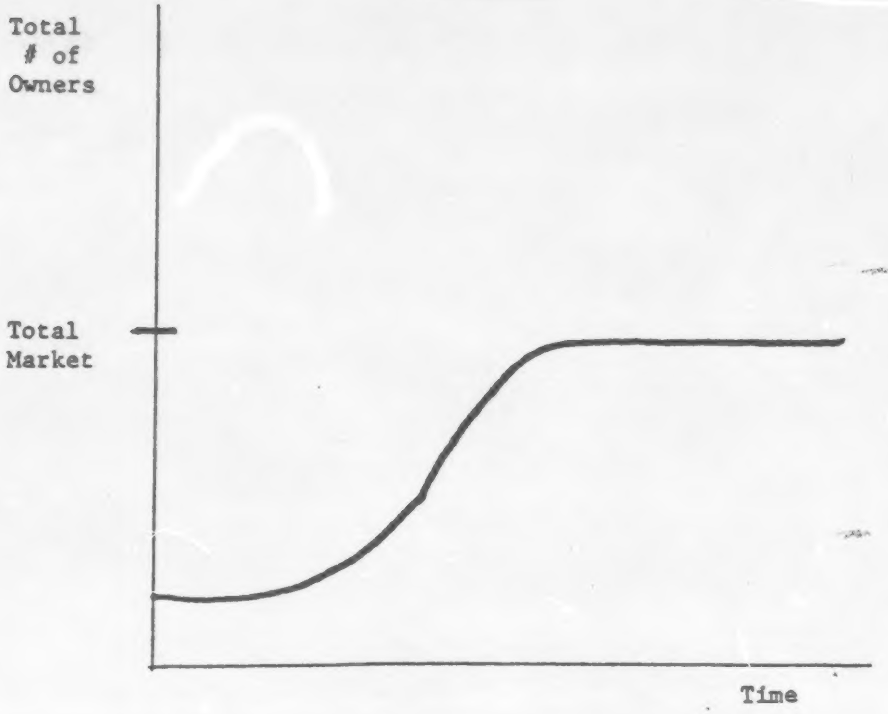


FIGURE 3-6

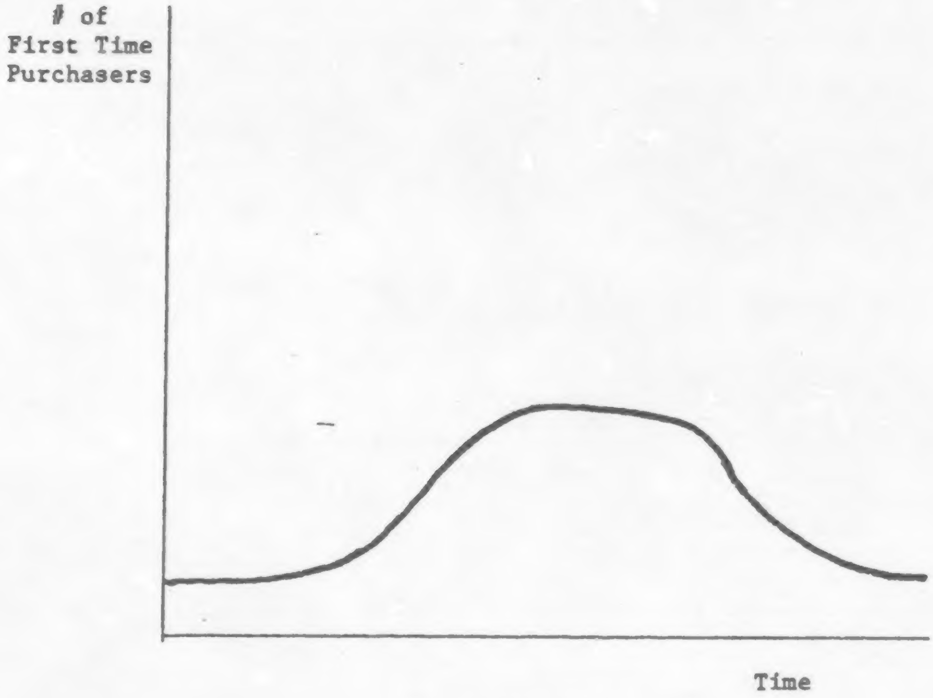


INCOME IN DOLLARS

FIGURE 3-7



a. Cumulative



b. Incremental

Life Cycle of Innovations - # of Owners of Product Over Time cumulative curve represents the number of individuals at any given time who own at least one unit of the product; the incremental curve shows the number of individuals who buy the product for the first time. The total market is made up of first-time buyers and repeat buyers. In this initial discussion, we shall concentrate on the first-time buyers; extension to repeat buyers follows.

4.1.1 Underlying Assumptions: The Bass Model

The shape of these curves is explained qualitatively in terms of the interaction effect among people. Those who adopt the innovation and like it tell other people, who then also adopt the innovation, etc. Initially, the product is bought by "innovators," that is, people who buy a new product because it is new. There are only a few of these; therefore, it takes some time for momentum to build up. At some point the "imitators," those who buy because the product has been demonstrated or otherwise made acceptable and attractive to them, start buying. The imitators constitute the great majority of potential buyers. Their entry into the market accelerates the adoption process. Toward the end of the process, there are very few new buyers, because all those who will buy (excluding additions resulting from population growth) have previously bought it. Thus, there is a build-up to a maximum among the first-time purchasers and then a decline. This view of the market carries with it the idea that there are different attitudes toward innovations that are reflected in purchasing. People are divided into innovators, early adopters, early majority, late majority and laggards.

This qualitative description can be quantified by using the mathematics of epidemiology. This was done by Bass (1969) who found that relatively simple epidemic models fit a wide range of consumer products, particularly high-ticket items. (Bass) The advantage of the Bass model is that it permits forecasts of sales over time based on a minimum of information. The Bass model also permits estimating the peak of the sales curve, that is, the timing of the downturn in sales to first time buyers. Bass, for example, predicted quite accurately the peak in the sale of color television sets to first-time buyers.

4.1.2 An Example: Electronic Calculators

Figure 3-8 shows the results of fitting the sales data for electronic calculators with the Bass model. The sales data were obtained from the March, 1978 issue of Merchandising magazine. The data are given in the form of percentage penetration of wired homes in the United States and of the number of wired homes each year. The Bass model states that the sales in year T, S(T) are given by:

$$S(T) = A + BY(T-1) - C(Y(T-1))^2$$

Y represents the cumulative sales through year T-1. A quadratic regression was fitted to the available data with the results shown in Figures 3-8A and 3-8B. The model forecasts a total market of 160 million units (7 calculators for every 9 people), peak annual sales of $22 million and peak sales in 1977.

4.2 The Autocatalytic Model

Over the years, many refinements have been made in the Bass model. A computer program that permits estimates to be made based on sales from initial

FIGURE 3-8a

ELECTRONIC CALCULATOR SALES DATA
FITTED WITH BASS MODEL

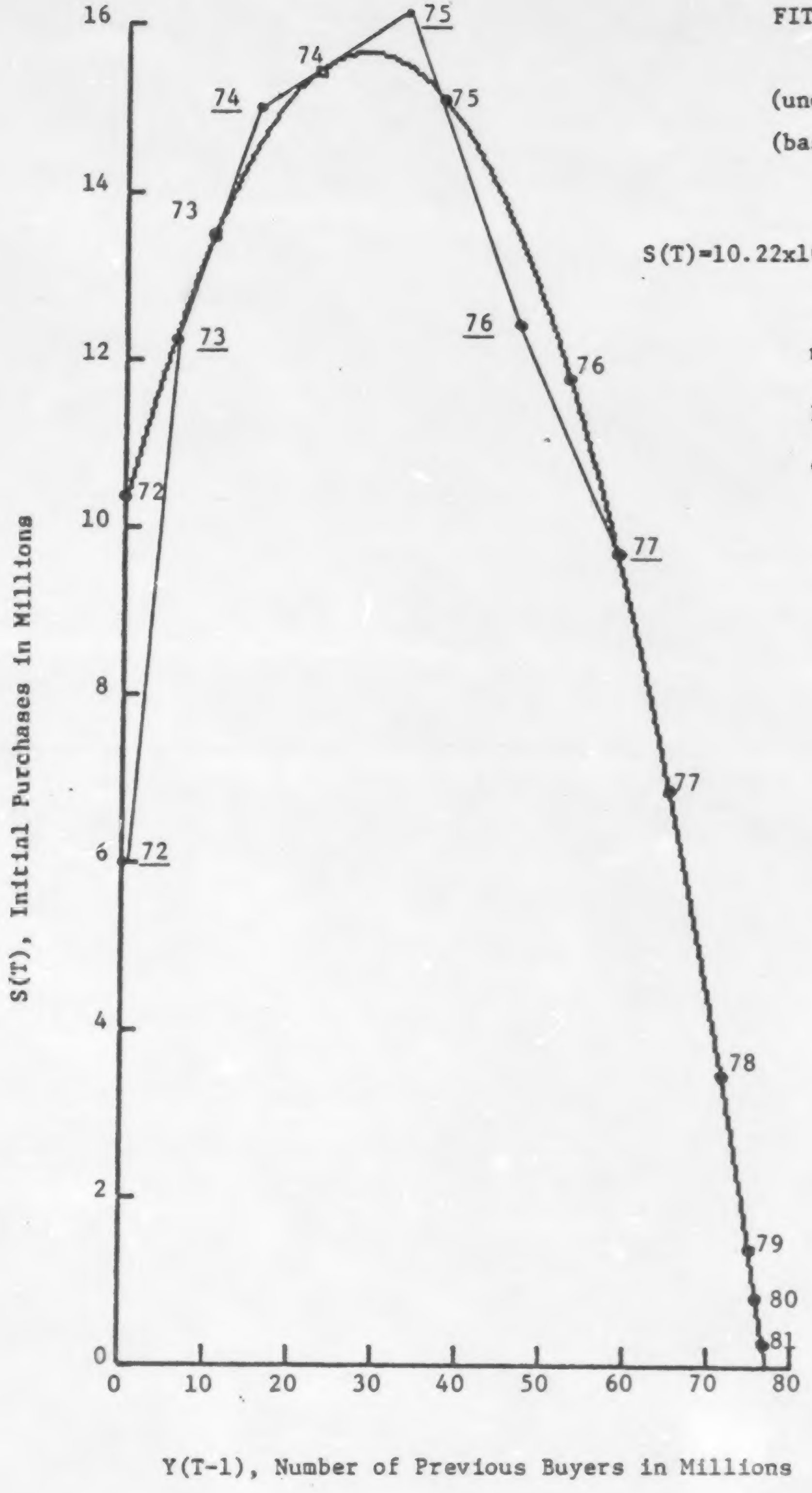
(underlined dates give actual data)
(based on the number of wired homes)

$$S(T)=10.22\times10^{6}+.3816y(T-1)-.6638\times10^{-8}(y(T-1))^{2}$$

m = 77.43 million

p = 0.1320

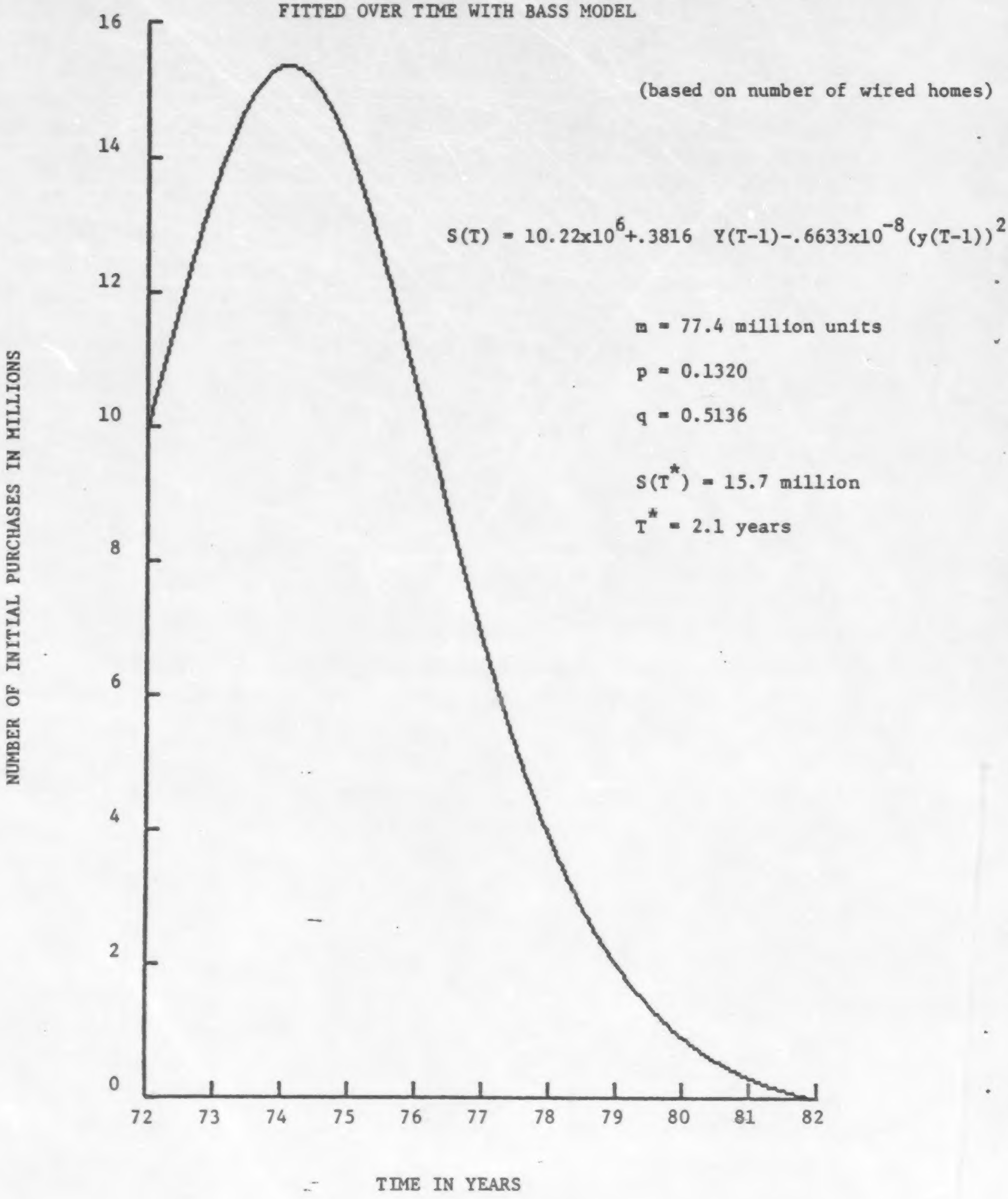
q = 0.5136



/Source: Merchandising: 10 Year Marketing Report 3/78/

FIGURE 3-8b

ELECTRONIC CALCULATORS INITIAL SALES
FITTED OVER TIME WITH BASS MODEL



(based on number of wired homes)

$S(T) = 10.22 \times 10^6 + .3816\ Y(T-1) - .6633 \times 10^{-8} (y(T-1))^2$

$m = 77.4$ million units

$p = 0.1320$

$q = 0.5136$

$S(T^*) = 15.7$ million

$T^* = 2.1$ years

years and total market size has been developed at the Ontario Institute for Studies in Education and has been made available to the project team. This version of the model is named the autocatalytic model since it follows the mathematics of autocatalytic chemical reactions which are similar to those of epidemics. It has the advantage that it requires estimates only of total number of owners, whereas the Bass model requires estimates of the total market, including repeat buyers.

Mathematically, the model predicts that S(t), the number of people who will adopt by time t, is given by:

$$S(t) = (N + n_o)/[1 + (N/n_o)e^{-pt}] - n_o$$

where N = total market size (all people who will ever buy their first unit)
n_o = carriers of the new idea (see below)
p = the rate constant, which is a measure of how fast the innovation spreads through the entire population of adopters.

The number of carriers, n_o, can be derived from the number of adopters in the first period, S(1) and the other parameters. It is given by:

$$n_o = NS(1)e^{-p}/[N(1-e^{-p})-S(1)]$$

The quantity n_o can be viewed as the effective number of adopters at time 0; these constitute the "seed" for the innovation.

The life cycle of the innovation, that is, the rate of adoption as a function of time, is the derivative of S(t) with respect to t and is denoted by s(t). The following quanities can be derived:

$$s(t) = p(N+n_o)Q(t)/(1+Q(t))^2$$

where $Q(t) = (N/n_o)e^{-pt}$

The time to maximum adoptions, $t_m = \ln(N/n_o)/p$
The maximum annual sales (i.e., sales at t_m) $= p(N+n_o)/4$

This form of the model has been shown to be quite accurate in predicting the life cycles of new products. Data indicate that for consumer items a typical value of the rate constant p is 0.5, although values between 0.33 and 0.6 have been observed. Commercial products seem to have p values in the range 0.45 to 0.6. We adopted a value of 0.5 as our nominal value and have run sensitivity analyses on p.

Figures 3-9, 3-10, and 3-11 show the annual sales that would be obtained for initial year sales of 50,000, 100,000 and 200,000 units and for total markets ranging from 1 to 100 million.

The effects of changes in the rate constant p are shown in Figures 3-12 and 3-13. Figure 3-12 plots annual sales for p values between 0.1 and 2.0, with all other conditions held fixed. It can be seen from this figure that as the rate constant, p, increases, annual sales increase initially, but reach a peak earlier. Both the magnitude of the peak and the rate of decline in sales after the peak is reached increase with p. Figure 3-13 plots the

FIGURE 3-9

ANNUAL SALES FOR VARIOUS MARKET SIZES

(INITIAL SALES OF 50,000 UNITS)

LIFE CYCLE: 1976-87

RATE CONSTANT: 0.5

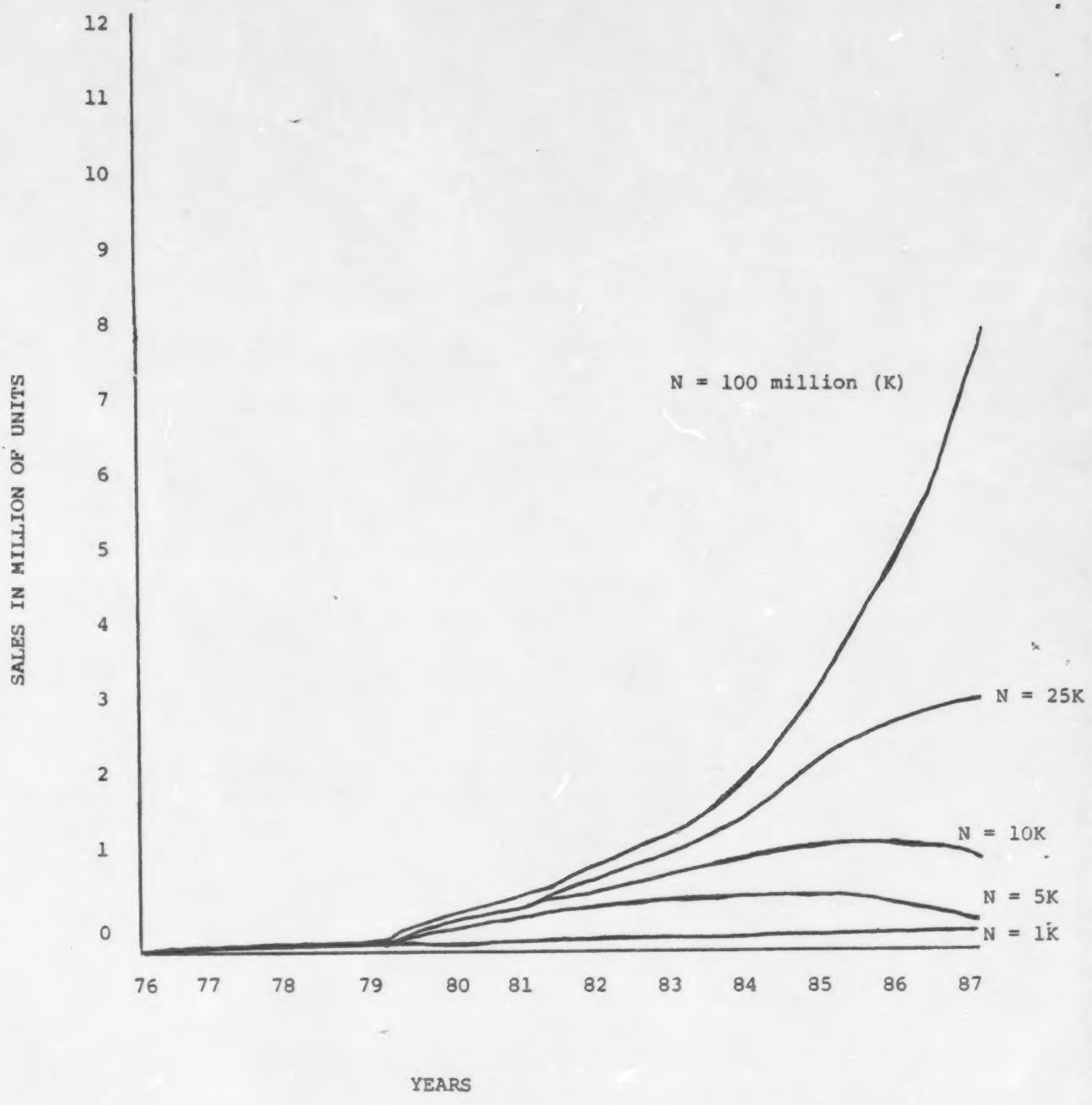


FIGURE 3-10

ANNUAL SALES FOR VARIOUS MAKET SIZES

(INITIAL SALES OF 100,000 UNITS)

Life Cycle: 1976-87

Rate Constant: 0.5

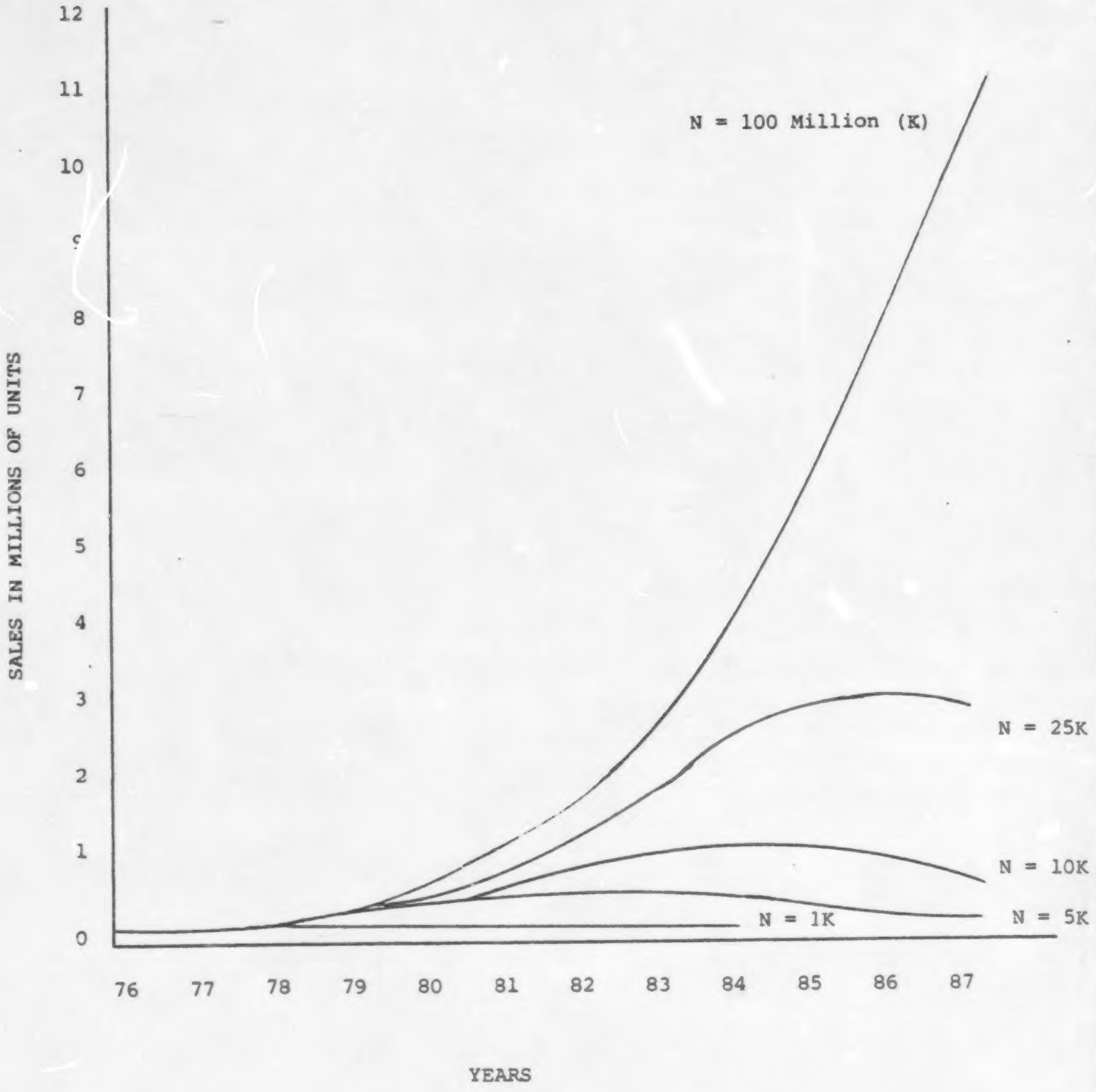


FIGURE 3-11

ANNUAL SALES FOR VARIOUS MAKET SIZES

(INITIAL SALES OF 100,000 UNITS)

Life Cycle: 1976-87

Rate Constant: 0.5

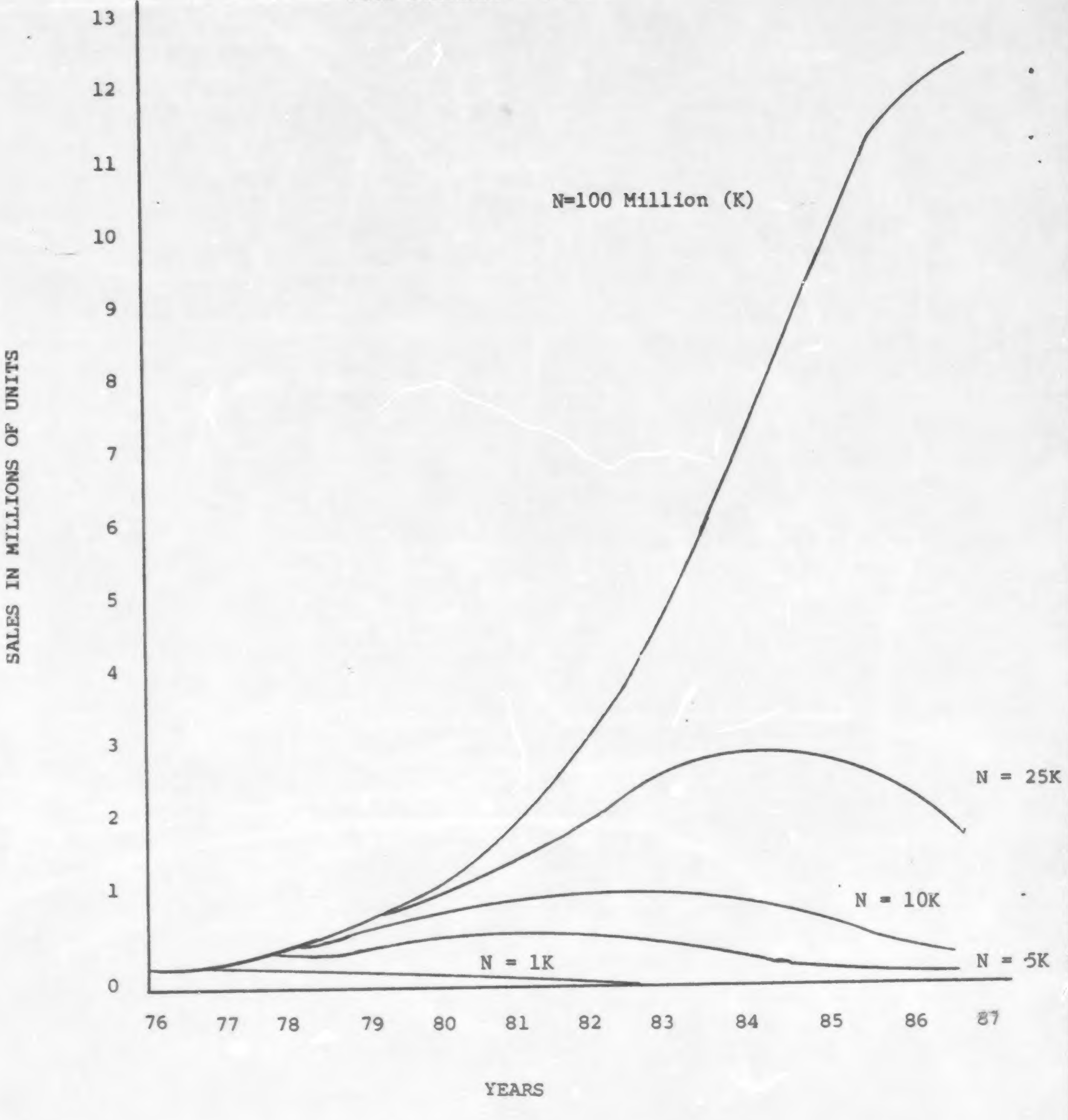


FIGURE 3-12

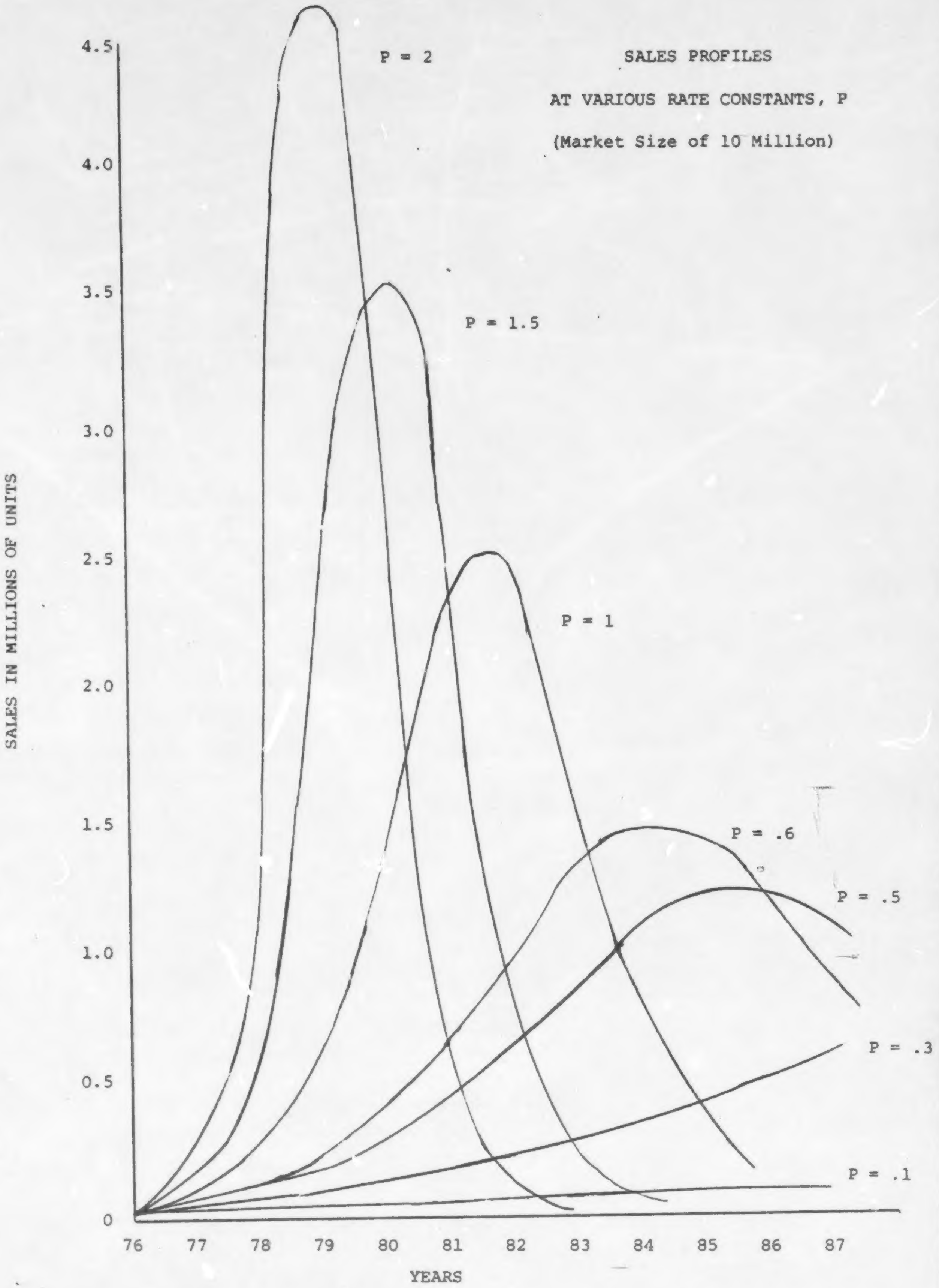
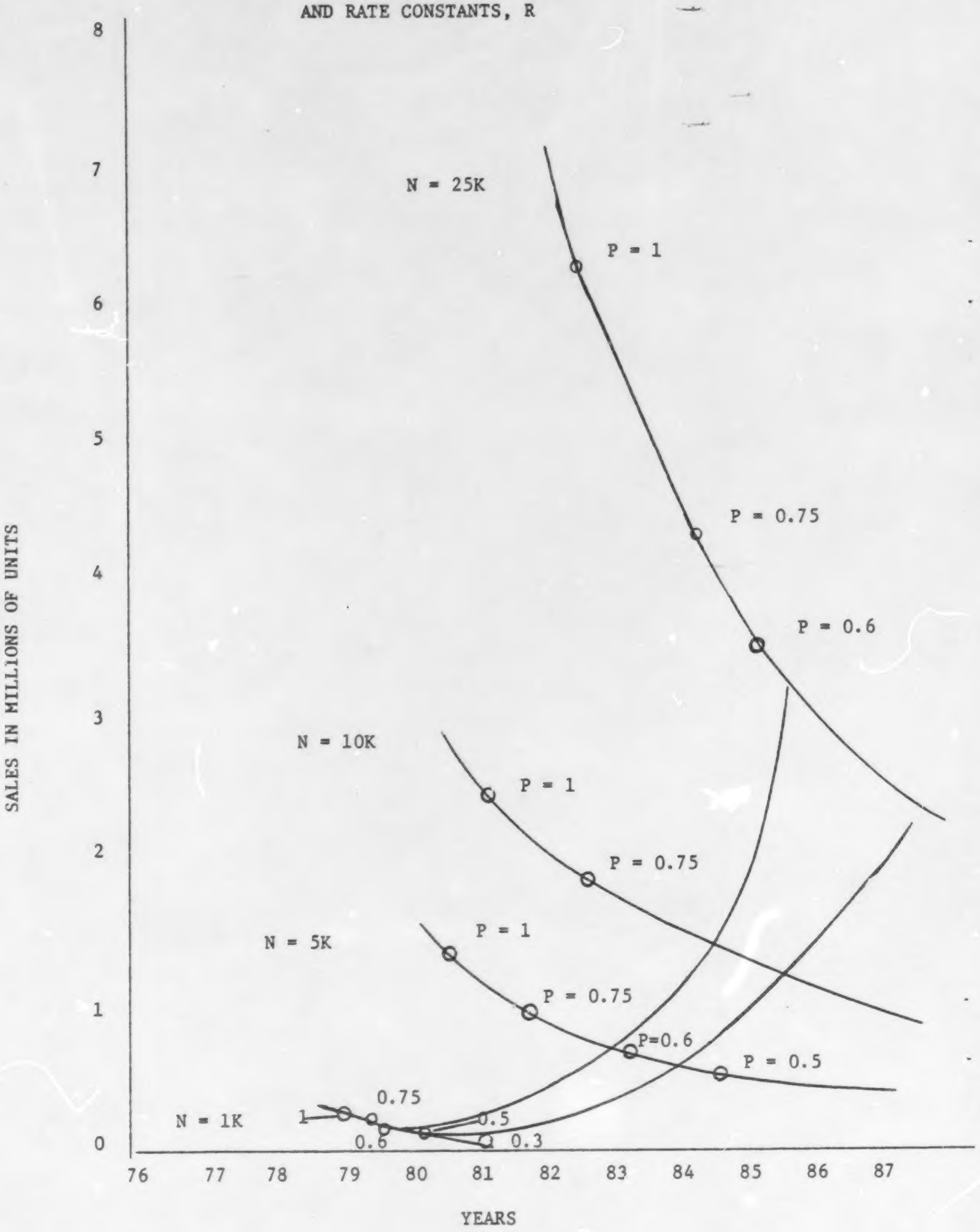

SALES PROFILES
AT VARIOUS RATE CONSTANTS, P
(Market Size of 10 Million)
P = 2
P = 1.5
P = 1
P = .6
P = .5
P = .3
P = .1
SALES IN MILLIONS OF UNITS
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0
76
77
78
79
80
81
82
83
84
85
86
87
YEARS

FIGURE 3-13

PEAK SALES CURVES
FOR VARIOUS MARKET SIZES, N
AND RATE CONSTANTS, R



maximum annual sales for values of p between 0.1 and 1 and for total markets between 1 and 25 million. Figure 3-13 also shows the increase in peak sales with the increasing total sales for fixed p values of 0.5 and 0.6.

4.3 A Simple Repurchase Model

Although the length of time that particular individuals (or organizations) take between initial purchase and purchase of a second personal computer (e.g., having faster computing capabilities or more storage or better display or networking capabilities) may be highly variable, for purposes of this simple repurchase model we assume that the time between purchases is fixed at the average time. That is, if the first unit is purchased at time T, the second unit is purchased at time T+T1, the third unit at time T+T1+T2, etc. where T1, T2,...may be different. For example, the first unit may be traded in after 2 years whereas the second unit (assumed to have higher capabilities) may be kept 3 years on the average. Furthermore, not all individuals who buy units will buy replacements. Thus, a fraction K1 may buy the first replacement and a fraction K2 of those who bought a first replacement may buy a second replacement, and so on.

If S(t) = number of units purchased in year t by first-time buyers

T(t) = total number of units purchased in year t (includes first time and repeat buyers)
K1,K2,K3... = fraction of buyers who buy the kth replacement
T1,T2,T3... = time between purchase of units

then, the purchases in year t will be

$$\begin{array}{lll} T(t) & = S(t), & t<T1 \\ & = S(t)+K1*S(t-T1), & T1\le t<(T1+T2) \\ & = S(t)+K1*S(t-T1)+K2*S(t-T1-T2), & (T1+T2)\le t<(T1+T2+T3) \end{array}$$

To illustrate this effect, Figure 3-14 shows the sales pattern that will result for the following conditions:

First time buyers: total market, N = 10,000,000
p = 0.5
Second time buyers: K1 = 0.5 T1 = 2 years
Third time buyers: K2 = 0.8 T2 = 3 years
Fourth and later purchases assumed to occur after ten years.

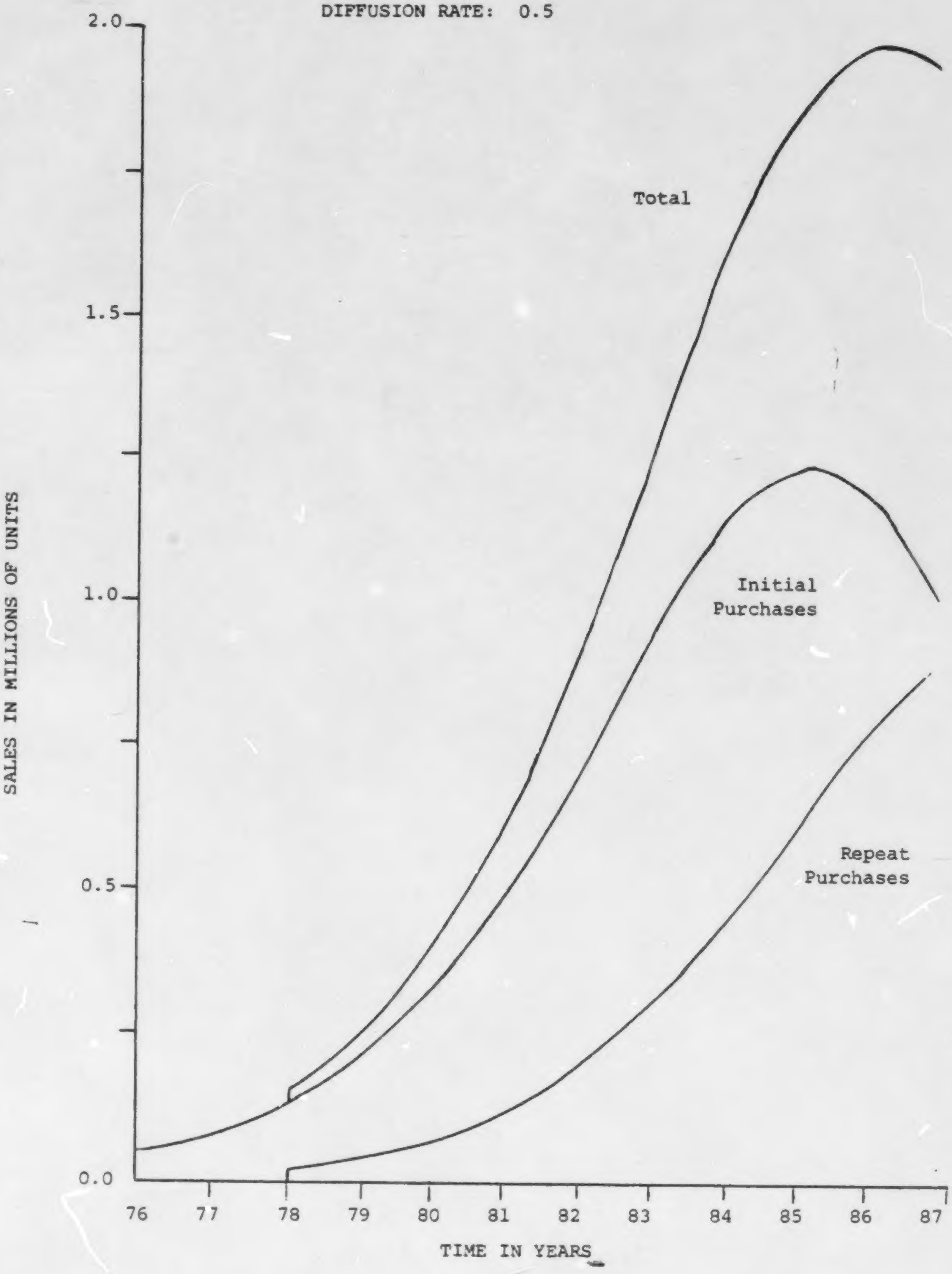
This repurchase model is based on the simplistic assumption that units are replaced in toto. At least initially, we believe this to be unrealistic, because of the hobbyist nature of the innovators who have been purchasing machines. These individuals are more likely to go through a process of continual upgrading, replacing and/or adding additional peripherals, replacing the circuit board and the chips to gain more CPU power, etc. These assumptions are borne out by our survey. This process is analogous to the component stereo system buyers who replace speakers or record changers or amplifiers but do not buy a complete new system. As the market matures, however, it is likely that many individuals will become involved who are not technically trained or inclined and who will replace the entire system when they upgrade, just as there are individuals who buy complete stereo consoles.

FIGURE 3-14

PERSONAL COMPUTER SALES

TOTAL INITIAL BUYER MARKET: 10 Million

DIFFUSION RATE: 0.5



5. ESTIMATING THE FUTURE PERSONAL COMPUTER MARKET

5.1 Estimates from Other Sources

As part of the work on estimating the size of the total market, project personnel have been gathering published and private estimates. These estimates are plotted in Figure 3-15. The points represent estimates of the total cumulative sales of personal computers by the beginning of the year indicated. Some of the data were obtained from sources we believe reputable but who asked not to be identified. Furthermore, since the estimates come from a variety of sources, there is no uniform definition of what is included under the heading "personal computer."

Using the estimated sales for 1976 (shown as the 1 January 1977 point) and the most conservative forecasts, a straight line may be fitted on a semilogarithmic scale. This line implies that annual sales would be 83% of the cumulative sales in all previous years (that is, a compounded annual growth rate of 83%). We believe that this rather remarkable growth can be sustained for a few years; however, we doubt that it can be sustained over a 10-year period. That is, we seriously doubt the forecasts of 100 million units within a 10-year period. As far as we know, no product has sustained such growth rates for such a long time period. This conclusion is also borne out by the experience with other consumer durables that indicates that initial sales growth rates do peak and that the market becomes a replacement market thereafter.

5.2 Development of Total Market Estimates

5.2.1 Fitting to Data

Both the Bass model and its simplification by the Ontario Group require estimates of the total market as inputs. As was shown for electronic calculators in Figure 3-8, the Bass model can be used to infer the total market if sales data for a number of years are available. In the case of personal computers, however, the available sales data are quite sketchy. The data are from different sources, fluctuate widely, and are difficult to interpret because they seem to be based on different definitions of the term personal computer. With at most three data points available (1976, 1977, and preliminary estimates of 1978 sales), fitting a quadratic such as the Bass model leaves no degrees of freedom for smoothing. Attempts to fit a Bass curve to the data have proved unsuccessful as have attempts to fit the simpler Ontario model which, it turns out, also requires a minimum of three data points. The problem is that the coefficients obtained from the regression fall outside the allowable ranges. Figure 3-16 illustrates the problem.

5.2.2 Future Market Components

Because of the paucity of data, we have had to turn to other, less data-dependent means of estimating total market size. These estimates depend on analysis of the characteristics of potential PC buyers. We have divided the potential market for PCs into four broadly- defined areas: the home, education, small business, and large organizations. Each of these areas has its own unique uses for PCs as well as some uses which it has in common with the others. Hence, to some extent the hardware and/or software of use in one area may be interchangeable for similar functions in another area. Table 3-22 shows some future uses for PCs, their applicability to each of the four areas, and the primary hardware and software hurdles, if any, to be overcome. Please

FIGURE 3-15

CUMMULATIVE PERSONAL COMPUTER

HISTORICAL & FORECASTED SALES BY SOURCE

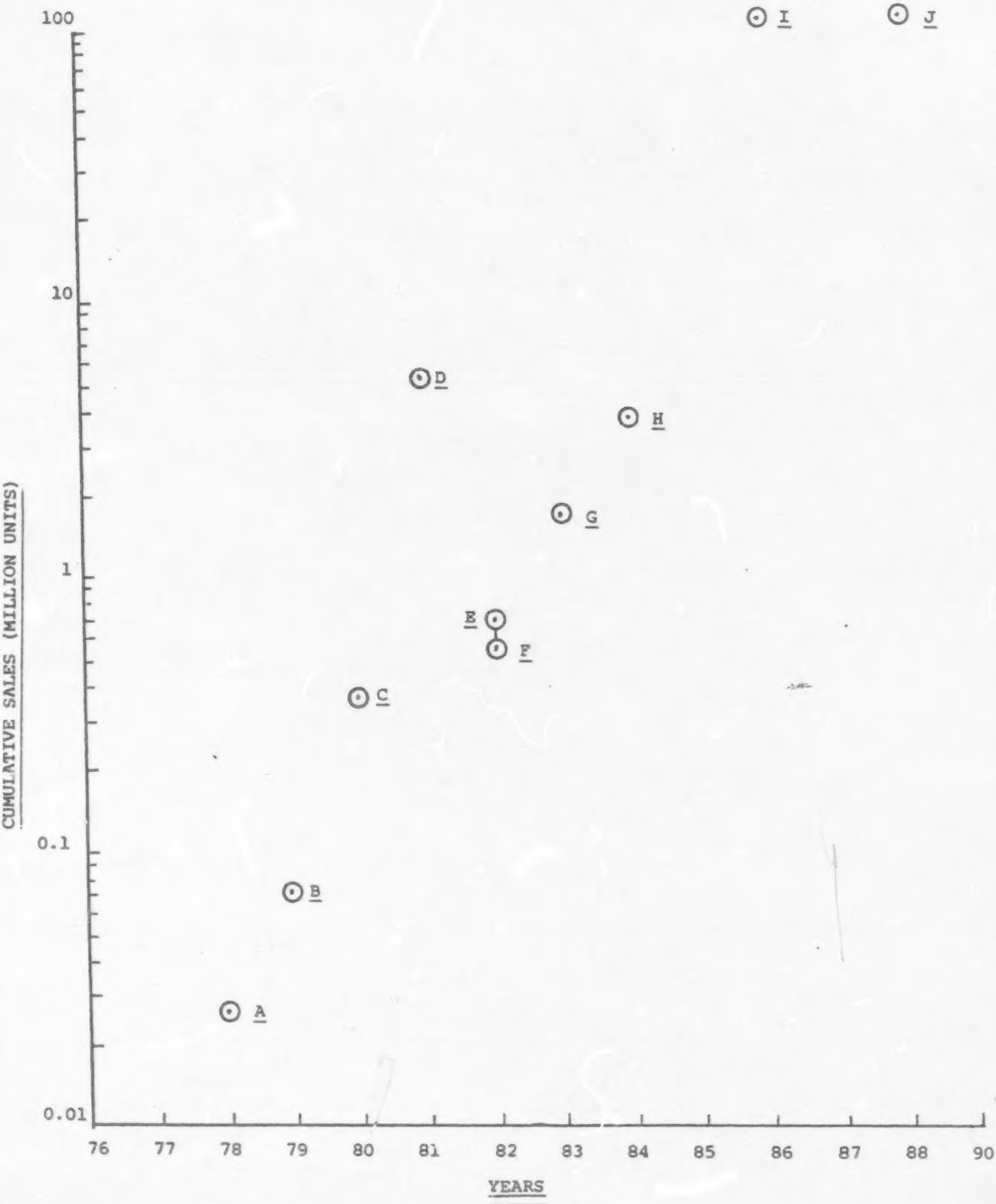


FIGURE 3-16

PERSONAL COMPUTER SALES
ESTIMATES FROM 2 SOURCES

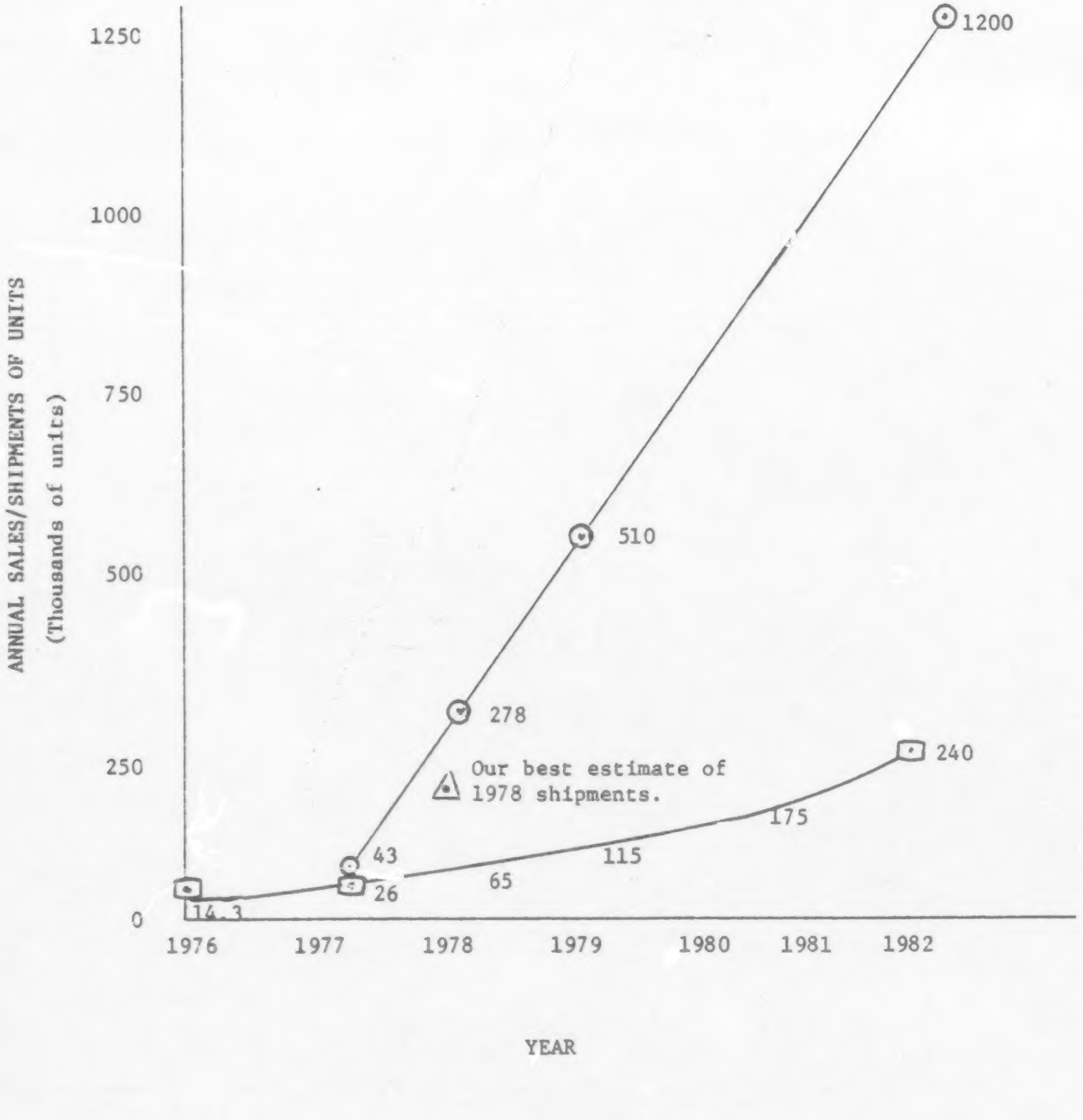


TABLE 3-22

USES FOR PCs, MARKET SECTORS, AND BARRIERS

					Economic/Technological Barriers	
USE*	HOME	EDUCATION	SMALL BUSINESS	LARGE ORG. (SMALL UNITS)	HARDWARE	SOFTWARE
COMMUNICATIONS					Cost reduction desirable.	Interface standards.
Autodialing	P	S	P	P		
Telephone Answering ("Dumb")	P	S	P	P		
Network Interface Processing & Electronic Mail	S	S	S	P		
EDUCATION						Significant lack of well designed software in all areas of application.
Computer Assisted Instruction	P	P	S	S/0		
Modeling	P	S	S	S/0		
RECREATION (Other than Education, Picture Processing)					Requires substantial cost reduction in digital sound hardware as above plus picture processing.	Will require increasing sophistication, versatility, user interface transparency in all areas of application.
Games	P	S	N	N		
Music	P	S	N	N		
Video Synthesis (Do-It-Yourself Cartoons, Sound Movies)	P	S	N	S/0		
ENVIRONMENTAL OR OTHER CONTROL					Requires low cost sensors, D/A converters, actuators.	Requires multi-tasking software.
Energy (Heating, Cooling, Air Conditioning, Electricity)	P	0	S	0		
Irrigation (Lawns, Fields)	P	0	N'	N'		
Appliance Control	P	S	S	N		

*
N = Not Used
N'= Not Used Except Farms
0 = Other Systems Provide Function
P = Primary or Frequent Use
S = Secondary or Infrequent

USE*	HOME	EDUCATION	SMALL BUSINESS	LARGE ORG. (SMALL UNITS)	Economic/Technological Barriers	
					HARDWARE	SOFTWARE
FINANCIAL						
Budgeting, Forecasting	P	P	P	P		Increased reliability, adaptability, user interface "transparency."
General Ledger	P	S	P	P		
Funds Transfer	S/O	S	S/O	S/O		
Tax, Payroll Accounting	T	O	P	P		
Investment Analysis	P	N	S	S		
INVENTORY/DATA BASE						
Personal Records (Medical, Educ., Finan., Etc.)	P	P	P	P/O		Increased reliability, adaptablity, user interface "transparency."
Inventory Goods	P	S	N	N		
Task Assignments	P	P	P	P		
Recipes	P	N	N	N		
Files	P	P	P	P/O		
Message Logs	P	S	P	P		
Visitor Logs	S	S	S	P		
Calendar	S	P	P	P		
PICTURE PROCESSING/GRAPHICS					Requires memory cost reduction, array processing(?) ergonomic interface design.	Greater sophistication, flexibility
Art Form	P	S	N	N		
Directed Communication (Sales, Reports, etc.)	S	S	P	P		
SECURITY						
Physical Intrusion, Structural (Incl. Fire, Smoke Detect.)	P	S/O	P	O	Requires low cost sensors, converters, actuators.	Requires multi-tasking software, sophistication in decision processing.
Countermeasures (Warning messages, Communication, Physical measures)	P	S/O	P	S		
Inhabitant Monitoring (Children; e.g., Sudden Infant Death Syndrome; Adults, e.g., Heart Monitoring)	S	S	N	S/O		

* P = Primary or Frequent Use
T = Primary or Frequent Use Exc. Payroll
S = Secondary or Infrequent
N = Not Used
O = Other Systems Provide Function

USE*	HOME	EDUCATION	SMALL BUSINESS	LARGE ORG. (SMALL UNITS)	Economic/Technological Barriers	
					HARDWARE	SOFTWARE
TEXT PROCESSING (Letters, Reports, Literature, Learning)	P	P	P	P	Requires lower cost for high quality printers in home market memory for voice interface.	Greater sophistication desirable, especially voice interface.

* P = Primary or Frequent Use

note that in the analysis we do not include the institutional hurdles which must be overcome. This is the subject of further research. The following is a brief description of each of the four market areas.

Home

The home PC (for our definition) ranges in complexity from a simple, self-contained system costing less than $150 to a complex, multiapplication, multicomponent system at the upper edge of our definitional constraints. The home PC will be used in a variety of ways; some already indicated in our survey data, some already discussed elsewhere, some to be discovered as our research progresses, and many of which we have not yet conceived (see Table 3-22). If current trends continue there will be some 86 million households in the United States in the late '80s.

Education

The size of the formal education system is expected to stay roughly constant through the eighties, although there will be a decrease in enrollment in primary and secondary schools in the early eighties. In general, however, primary and secondary education will include a total of 2.5 million classrooms in order to teach approximately 50 million children. Postsecondary education applications might have a comparable level of demand.

Small Business

In this category we include professional offices, which by the mid- to late eighties will account for 2% of the labor force and about 1.5 million offices, as well as other service-oriented small businesses, wholesale and retail trade, finance, etc, for a total of about 4 million firms. We use the criterion of fewer than 100 employees as the "small" business dividing line.

Large Organizations

The functions performed by the PCs in large organizations, public and private, will be quite similar to those in small businesses (word processing, data base management, accounting, etc.). The PC will appear as the work horse local unit in the office of the future, eventually replacing the familiar electric typewriter. [NOTE: In our final estimates we have combined the last two categories into a single one: the Office user group.]

5.2.3 Estimate Methodology

As has already been mentioned, our approach has been to develop estimates in each of these three areas based upon reasonable assumptions concerning the characteristics and numbers of potential personal computer buyers rather than upon existing factual data. For example, the estimate of the total number of personal computers to be used for business purposes can be derived by several means: as a fraction of total information workers likely to directly operate a PC, by the number of businesses with more than a certain level of annual receipts, by the number of college graduates in business, science and engineering, etc, by the fraction of the gross national product likely to result from data processing using small machines, etc.

To take the first case as an illustration, we expect that there will be roughly 50 million information workers in the mid- to late eighties (an information worker is an individual whose job consists largely of information manipulation and/or transfer activities of various sorts). (Porat, 1977) At least half of these information workers will have their jobs associated with the transfer of digital data of one form or another as computer technology develops. For various reasons some of these workers will not have a continual need for personal interaction with a computer, although we estimate that about two-thirds of them will. Some will have more than one PC. This leaves a total, at the saturation level, of at most about 35 million and at least about 10 million possible users of personal computers in business operations. Because the rate of technological change in the microcomputer industries is expected to continue through the eighties and into the nineties, we can expect about a three-year replacement cycle for PCs in business applications, comparable to today's cycle for office computer equipment. Hence, our nominal estimate is that about 4 million PC units might be sold annually for business purposes in the late 'eighties. About two-thirds of these could be in large business organizations and one-third in small businesses (including farms). The other means of estimation listed above, rough as they are, tend toward the same annual level for a saturated market of about 4 to 6 million units per year for a three-year replacement cycle.

A similar rationale can be used to estimate the number of households in which there could be personal computers. We estimate that roughly half of the households in the United States could have a personal computer at the end of the eighties. This amounts to some 40 million units. One way of arriving at this estimate is by noting that essentially half of the individuals now graduating from high school go on to college. By the mid-eighties, many if not most of these individuals will have had exposure to and experience with computers, including personal computers. This portion of the population, together with those whose exposure to computers occurs through business situations, is likely to grow to include at least half of the population by the late eighties. As we have seen from our surveys, prior exposure to personal computers in a work or educational environment is highly correlated with eventual ownership of a PC. Ultimately, we expect personal computers, of one sort or another, to be as prevalent as TV sets. Hence, our high growth estimate reflects a saturation level of some 80 million first-time buyers in the U.S.

Because of the nature of our research, we are less concerned at this point with achieving high accuracy in individual forecasts of the size of the PC market than we are with estimating the possible range of sizes of the market, since the public policy aspects and markets size are interrelated. For example, if the PC market were to be limited to hobbyists, computer enthusiasts, and high-technology small businesses, it could not be expected to grow substantially beyond its present size. Nor would the size of the market be sufficient to attract major manufacturers into the industry or to allow existing manufacturers to grow to a size where substantial, learning-curve-induced, economies of scale might be achieved, with concomitant reduction of the costs of units of a given capability. Similarly, there would be less incentive for software developments oriented toward the average consumer, and so on. The public policy implications in this case could be limited to some issues of computer crime, some small changes in employment patterns, etc., but in general would not be expected to be nationally significant. On the other hand, if millions of PCs exist and are in active use - even if the numbers are not so high as those show here - , the potential for widespread effects on education, health care, computer related crime, consumer fraud, changes in the labor market and in the allocation of resources within the economy, energy use, etc. all begin to become significant. Based on our experience to date, we expect this latter case to be the most probable one for the next decade - if the market acts to take more advantage of the opportunities.

5.2.4 Nominal Estimates

With all of the above as a preface, we come to our nominal estimates for the three PC submarkets of the future. These estimates form an "envelope"; a set of minimum and maximum growth trends, within which we expect the actual market growth to occur (with all the caveats just discussed). These are the estimates used for the policy analyses of Volume III.

The nominal estimates are graphed in Figures 3-17 through 3-25. They show the projected annual and cumulative sales in units, and the annual dollar volumes (1980 dollars), for FIRST PURCHASES of PCs over a 25-year period. These graphs were derived using the model discussed in section 4.2 and the saturation level market sizes discussed above. Actual annual sales will be higher than those shown in proportion to the repurchase factors discussed above. In summary, for the late 1980s (NOTE: all dollar values are in constant, 1980 dollars):

Consumer (Home)

Because of the increasing ubiquity of information technologies we estimate that the home market will approach that of television near the turn of the century, provided that a number of technological problems, particularly those of software, are resolved. The nimber of first-time buyers will peak in the early 1990's, with annual sales of from $1.25B to $3.3B in the peak years. Initial unit prics will average about $1000 in the early '80s, decreasing to just over $300 near the turn of the century. Although two-thirds of PC unit sales will be in the $200 range a greater dollar contribution will come from higher priced units, resulting in athe higher average. Total software sales in this market will stabilize at about one-fourth the magnitude of the hardware sales. Therefore, the total annual Consumer PC market in the late eighties, for this estimate, will range between $1.5 and $4 billion for first-time buyers.

Education

The average annual budget for books, materials, supplies, etc. for each classroom is approximately $5,000. We anticipate that there could be an average of one PC per classroom by the late 1980s, although actual physical distribution will tend to be concentrated in one or two classrooms per school building. The initial distribution of PCs will be in school administrative offices, a process which is already under way. Enrollment of college students in the mid-eighties will be about 13 million. Here the number of personal computers per student could be higher, roughly one for every five students. Assuming a four year replacement cycle, the annual market for PCs in the formal educational system could be as high as 1.3 million units. However, our more conservative appraisal of the possibilities of the education market (cf. Vol. III) sets the peak rate of first-time purchases at from 160,000 to 550,000 units at about the turn of the decade. Note: this estimate is for purchases by the formal education system. A sizeable component of the education market is included implicitly in the home applications segment.

FIGURE 3-17

CONSUMER COMPUTER CUMULATIVE SALES TO FIRST-TIME BUYERS

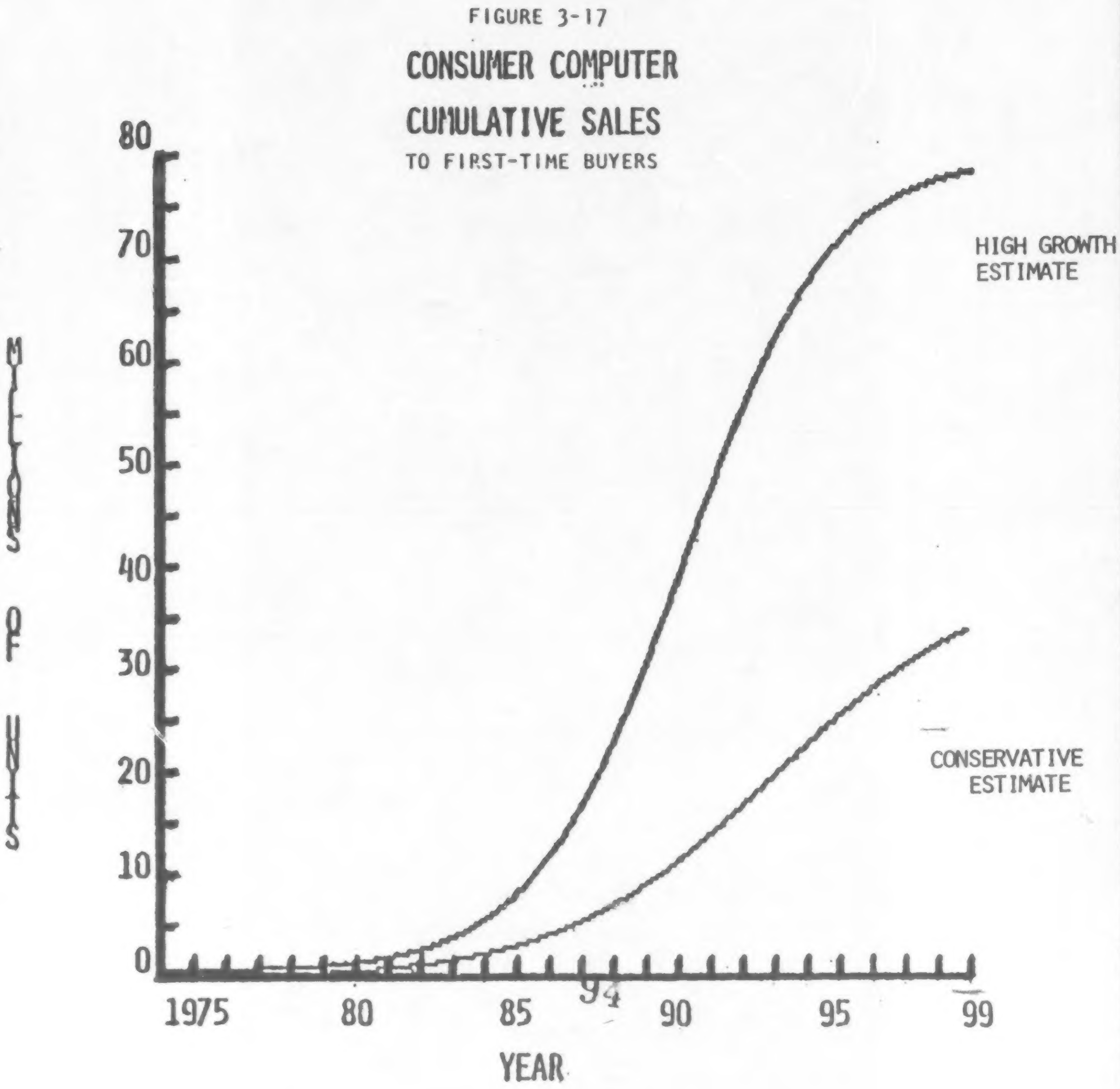


FIGURE 3-18

CONSUMER COMPUTER ANNUAL SALES

TO FIRST-TIME BUYERS

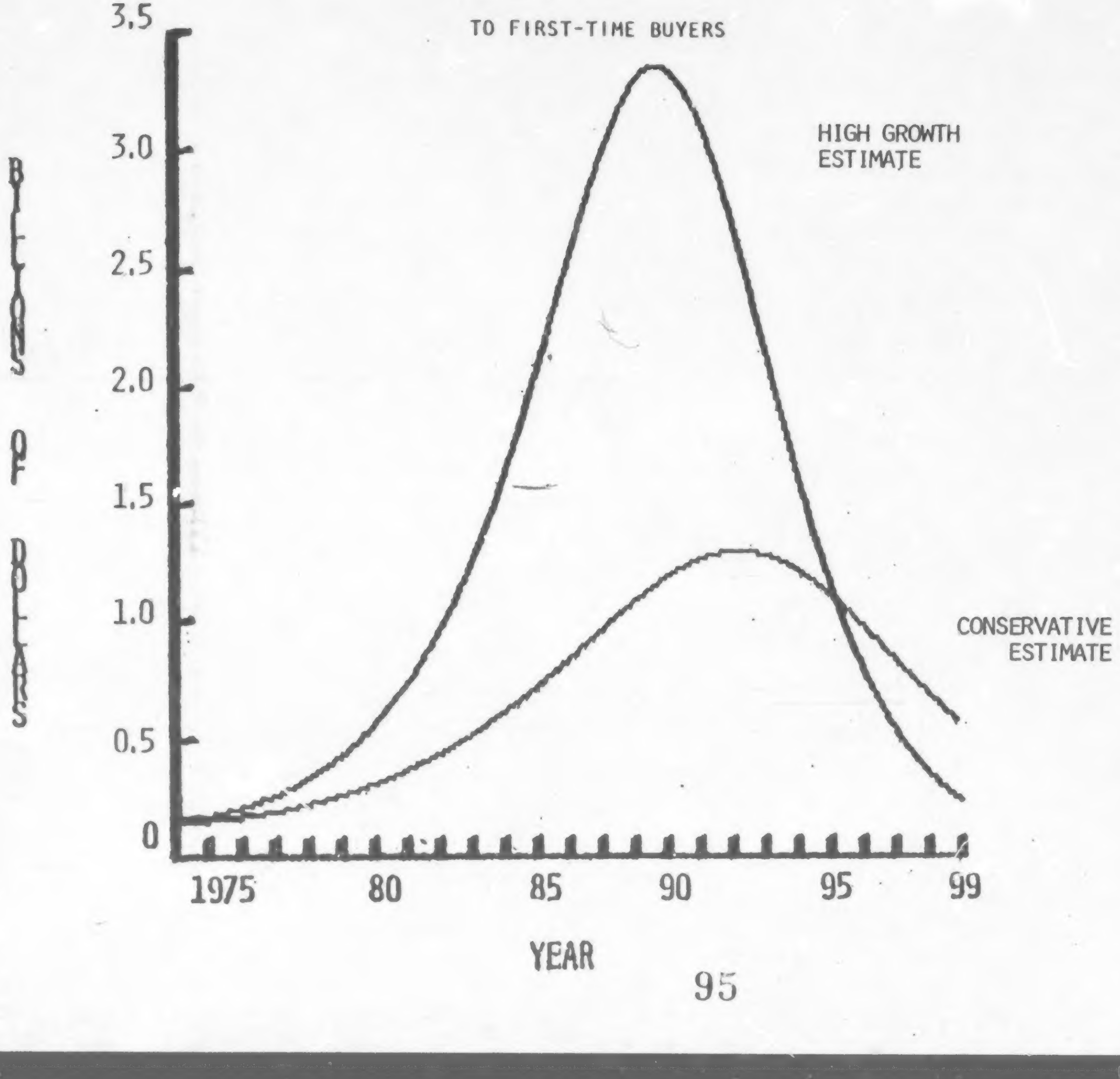


FIGURE 3-19

CONSUMER COMPUTER ANNUAL SALES

TO FIRST-TIME BUYERS

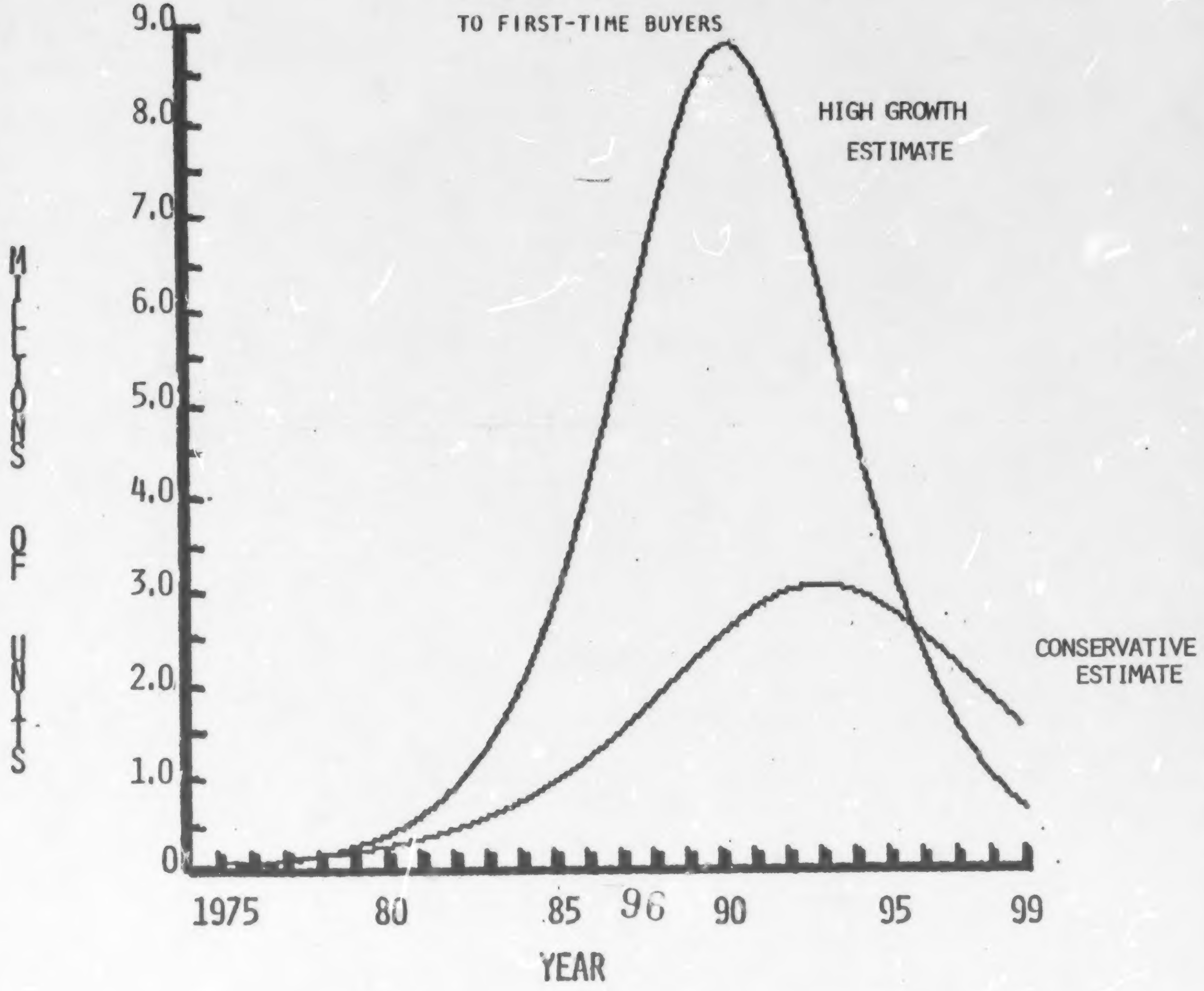


FIGURE 3-20

PCs IN EDUCATION

CUMULATIVE SALES

TO FIRST-TIME BUYERS

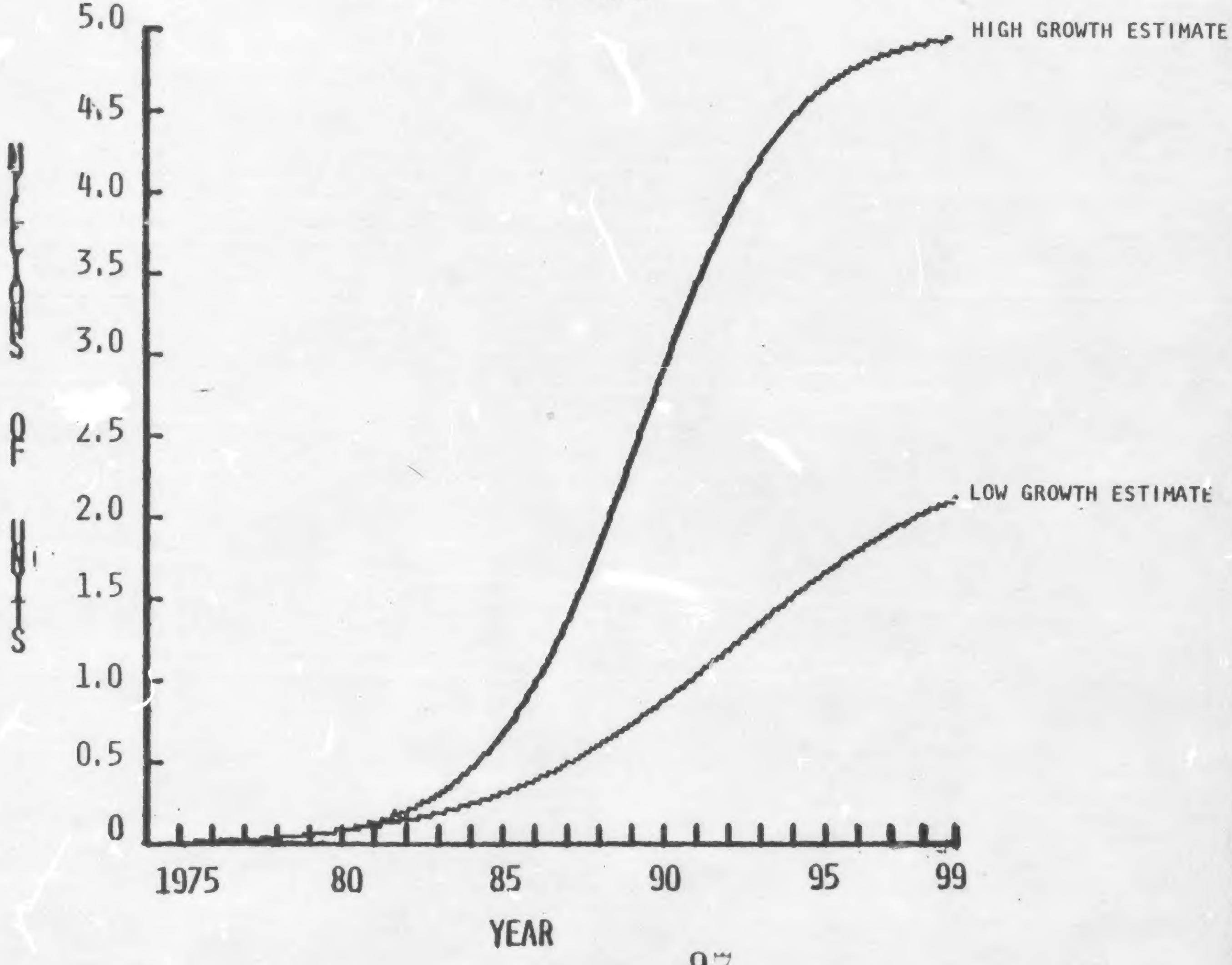


FIGURE 3-21

PCs IN EDUCATION

ANNUAL SALES

TO FIRST-TIME BUYERS

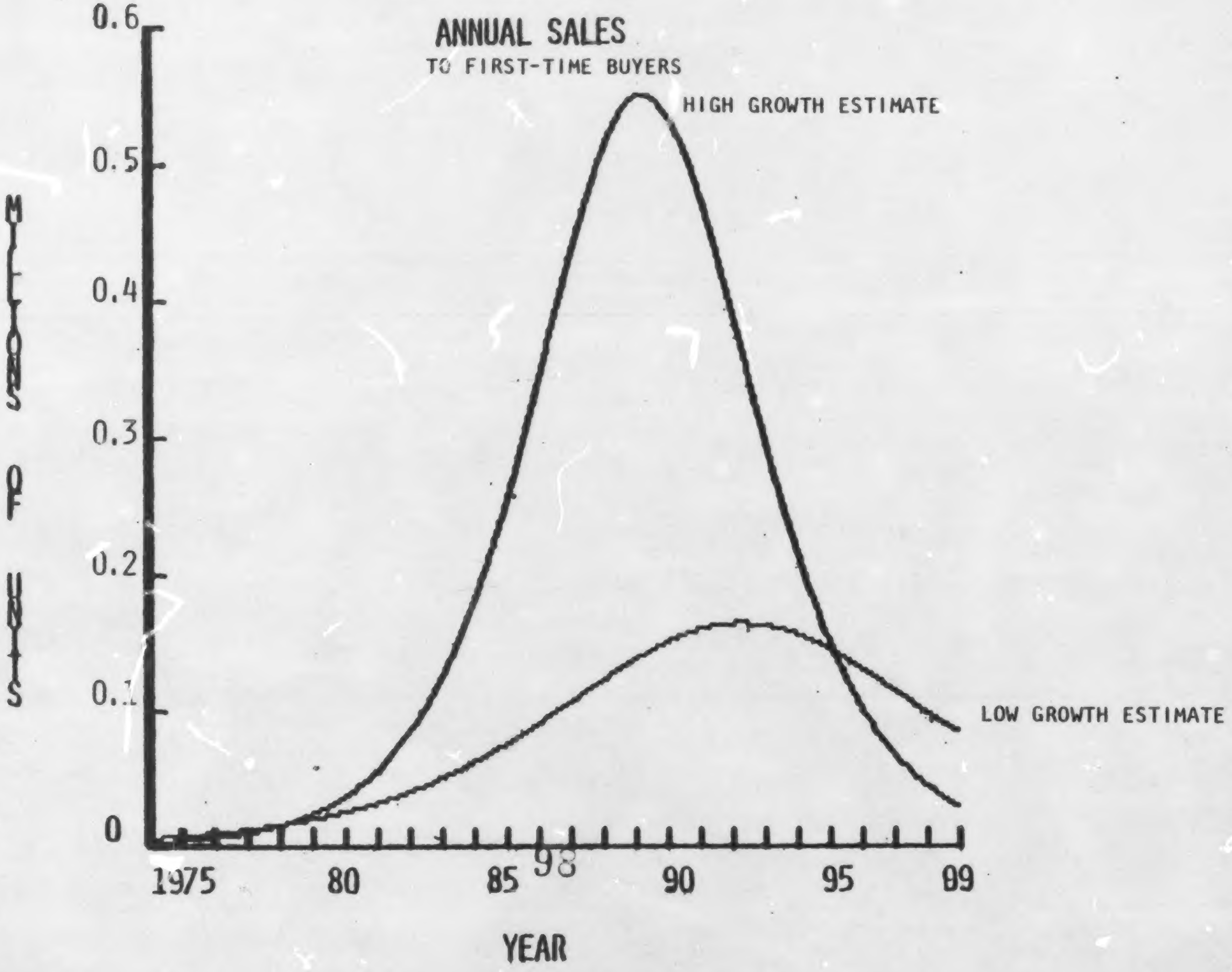


FIGURE 3-22

PCs IN EDUCATION

ANNUAL SALES
TO FIRST-TIME BUYERS

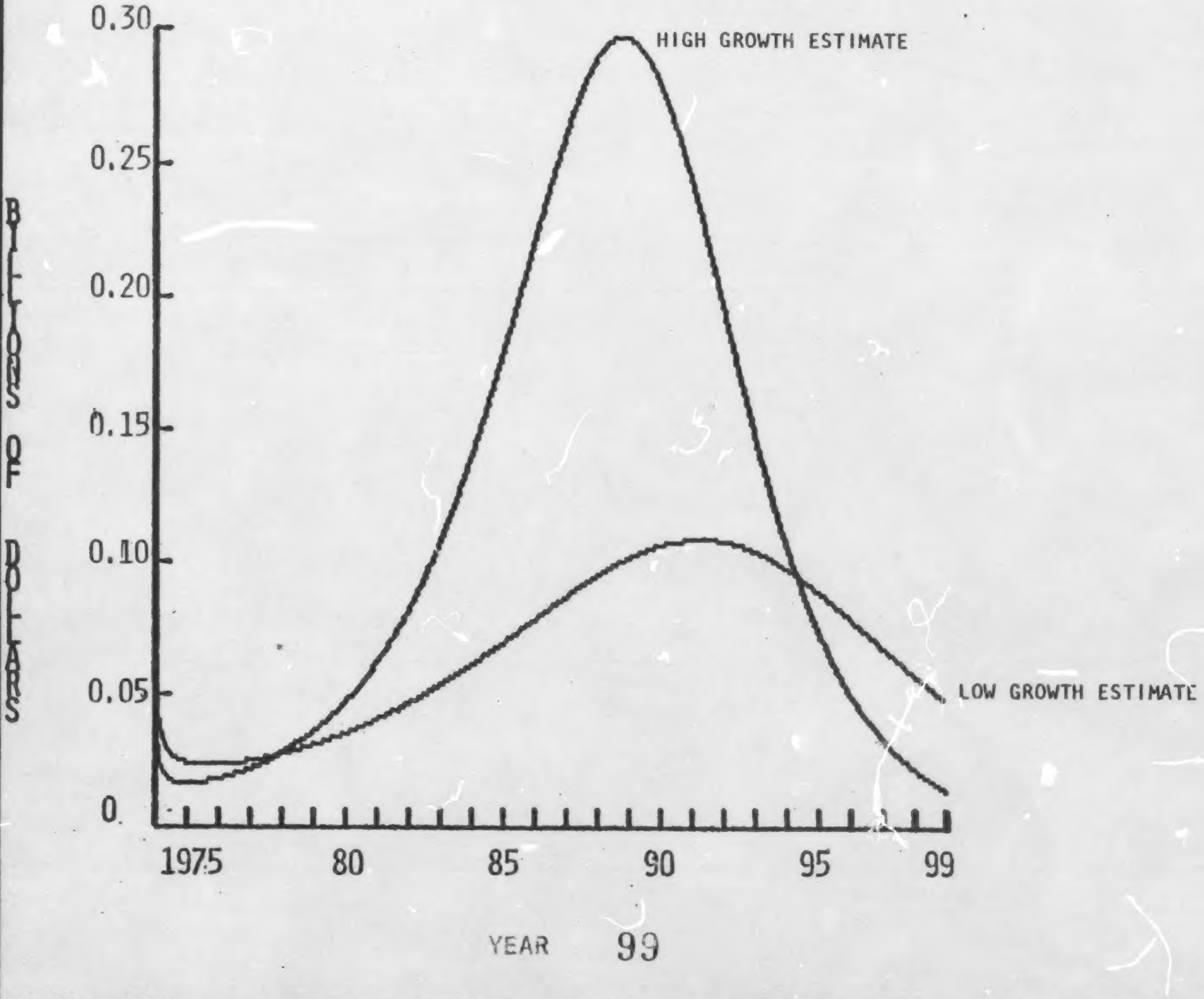


FIGURE 3-23

OFFICE COMPUTER
CUMULATIVE SALES
TO FIRST-TIME BUYERS

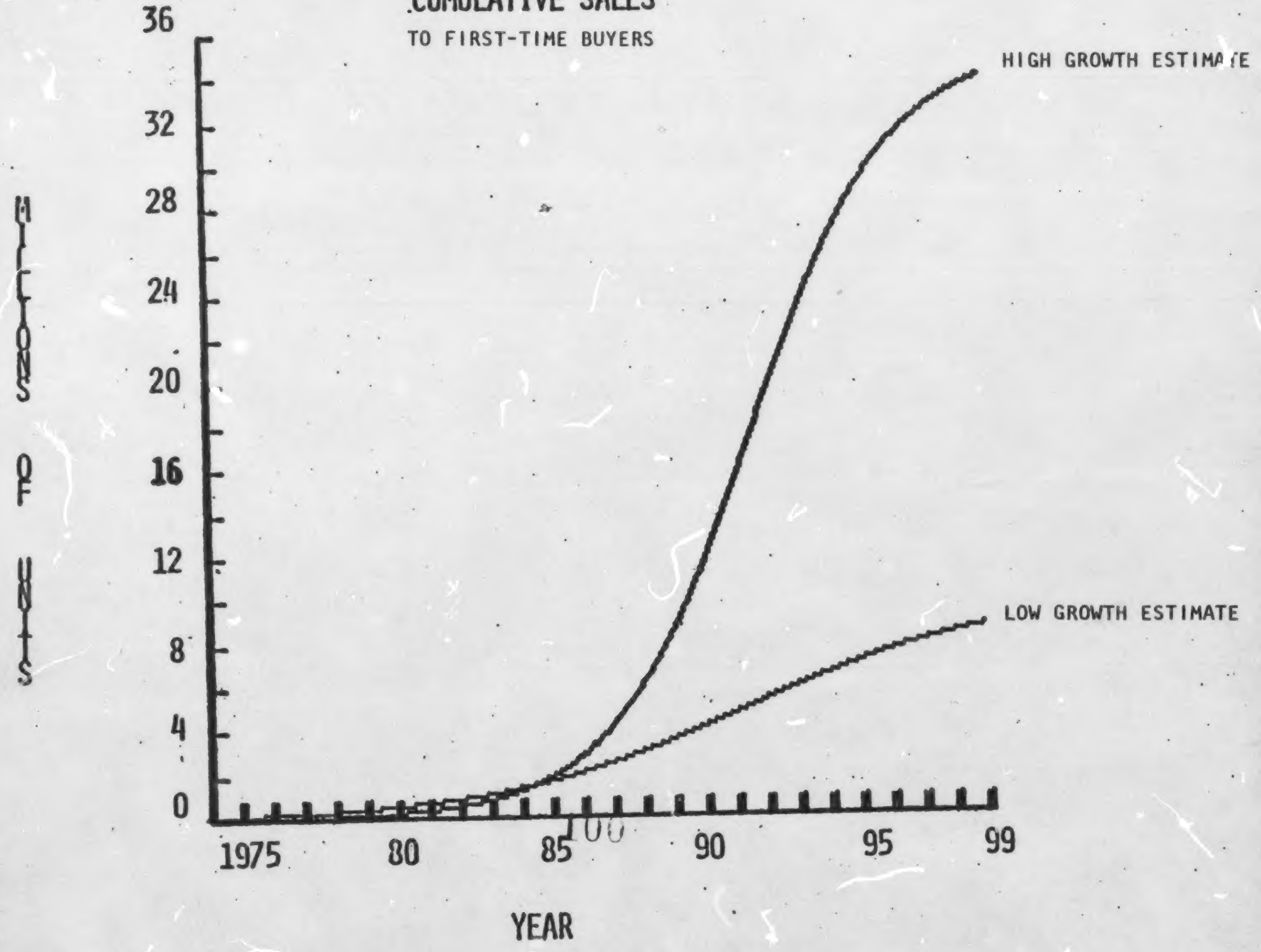


FIGURE 3-24

OFFICE COMPUTER
ANNUAL SALES
TO FIRST-TIME BUYERS

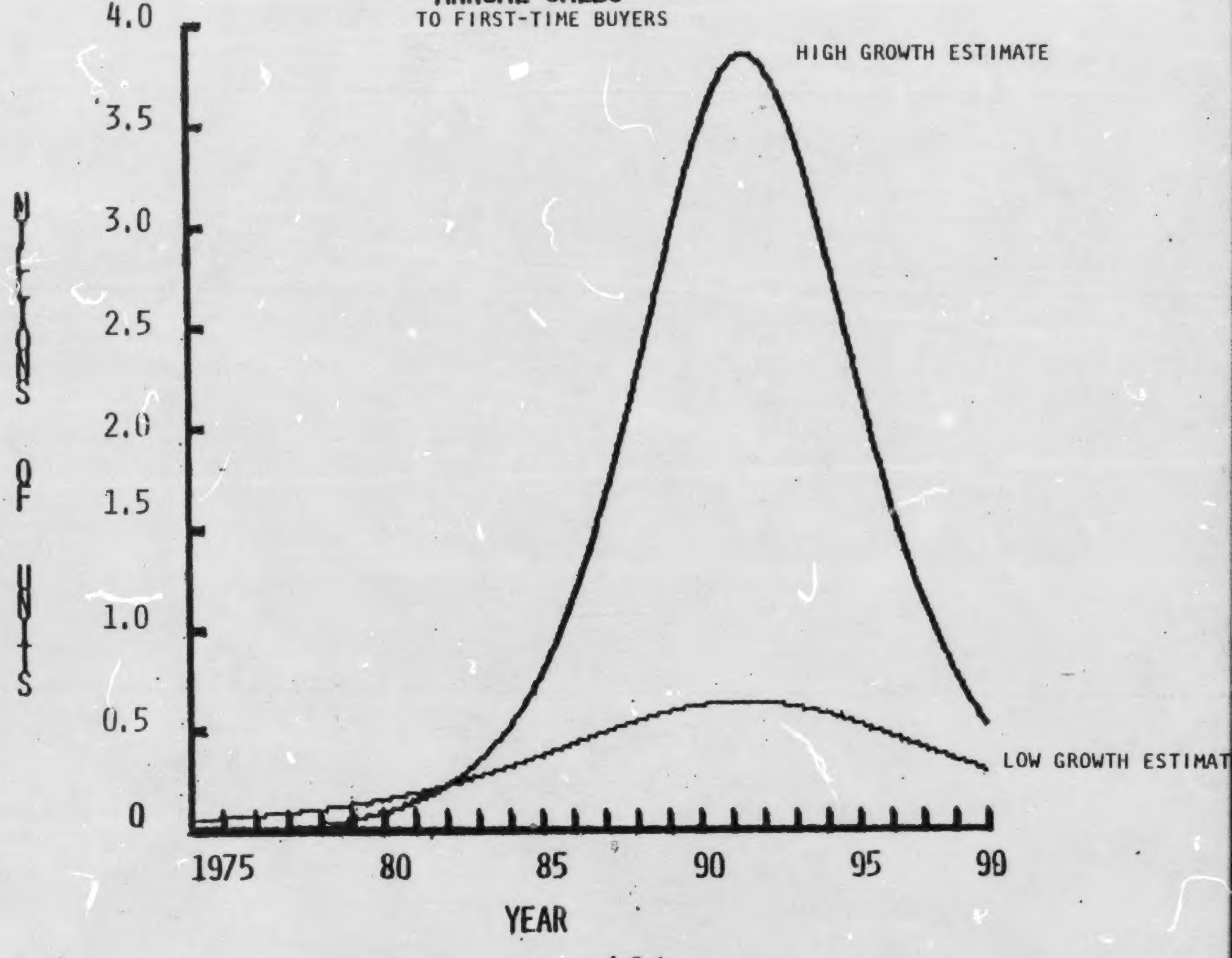
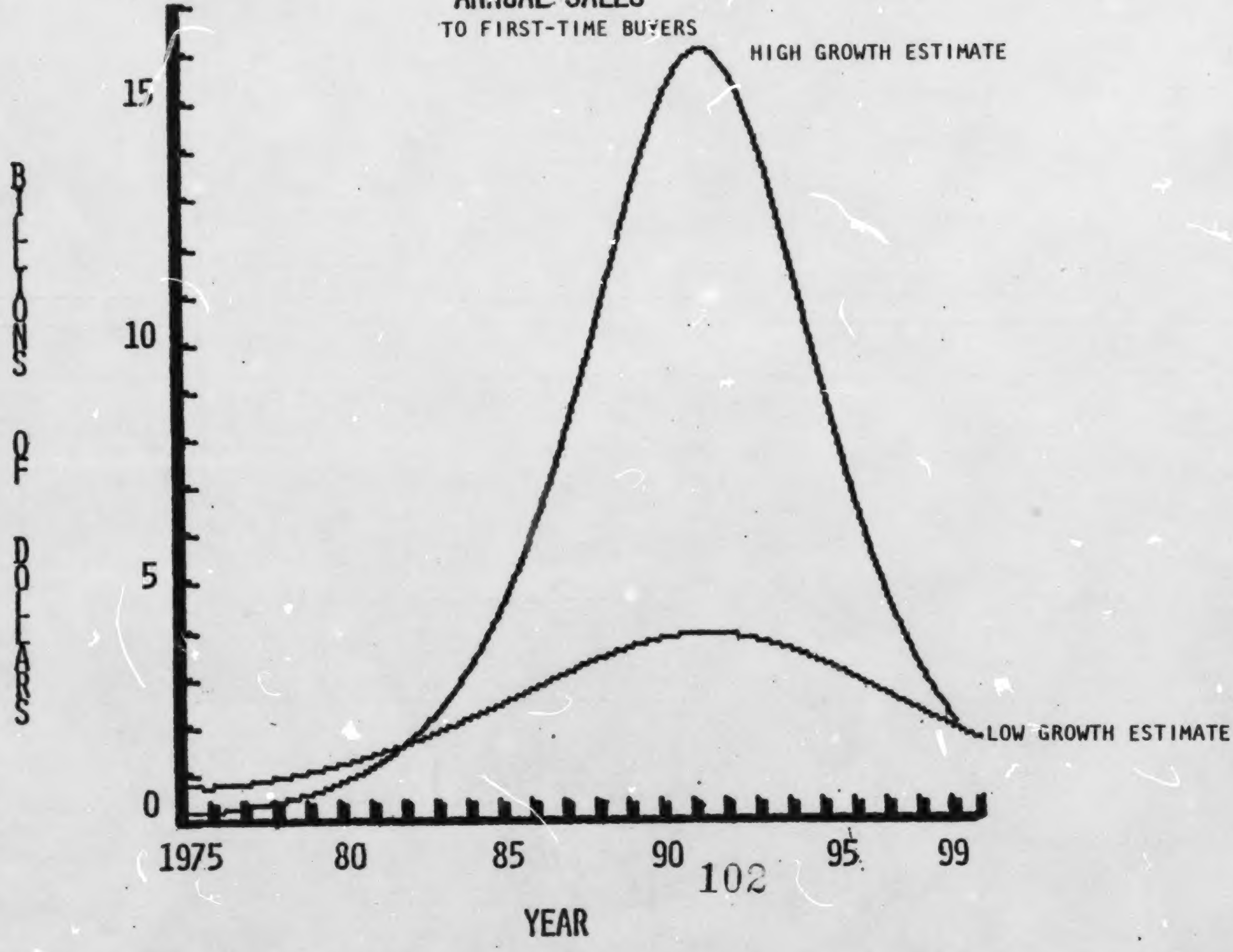


FIGURE 3-25

OFFICE COMPUTER

ANNUAL SALES
TO FIRST-TIME BUYERS



Office

Small Business. We estimate, as a first approximation, that annual sales of PCs to first-time small business users by the mid- to late eighties will be the equivalent of from 200,000 to 1 million units, with an average price of $1000, compared with a price for a contemporary small business PC of about $7000 The tradeoff here and in other areas is that the actual market could be a smaller number of more expensive units, but with about the same total market value.

Large organizations, both public and private, will account for another 400,000 to 4 million unit sales annually to first-timers. Under three-year replacement cycle conditions, an additional 2.5 million to 4 million units might be sold to large organizations, according to our nominal estimate. Unit prices for both small and large businesses will average from $4,000 to $6,000 as emphasis increase on office productivity improvement. We estimate that the annual hardware market in the early 'nineties could be above $15 billion. Both small business and large organization software markets will be of equivalent size to the hardware markets (although in large organizations the work may be done internally and not show up in sales figures).

Fortunately, if we can believe the application of past experience (via market modeling methodologies) to the case of personal computers, as shown by these nominal estimates, we still have some time to assess thoroughly the implications of their use before the situation grows beyond control. It is clear from these estimates that the size of the PC market is likely to attract some substantial stakeholders and produce associated policy issues.

PART IV

SOME THOUGHTS ON POTENTIAL SYSTEM CONFIGURATIONS AND ALTERNATIVES

The focus of our research has been on the technology of microprocessor-based general purpose computer systems. The implicit assumption in the material presented thus far is that the personal computer of ten years hence will have substantially the same functional characteristics, if not outward appearance, as the personal computer of today. This is not necessarily the case. If instead we examine the future from the standpoint of information processing needs rather than applications of existing systems to satisfy them, we may come up with some different alternatives, or at least different manifestations of similar alternatives. Some of the possibilities are as follows.

1. Network Information Services: Telecommunications Based Alternatives

The primary immediate alternative to personal ownership of a stand-alone computer is the use, through telecommunications linked time sharing, of large computers located elsewhere. There are several variations on this theme, the oldest of which, time sharing of large computer systems for computational and text editing work, has been practiced by professionals in the computer field for almost two decades. Other types of services, more consumer oriented, are evolving in the United States, Europe, and Canada. The following are some of these options:

1.1 Commercial Computer Time Sharing

Large, "mainframe" computers have substantially more computing capacity than available microcomputers. Because of the nature of the technology, the latest mainframe computer will always be substantially more powerful than the latest microcomputer, for reasons discussed in Part II of this volume. Furthermore, economies of scale do hold in the comparison between large and small computers. The cost per instruction processed by a large mainframe can be an order of magnitude or more lower than the cost per instruction processed by a microcomputer. Furthermore, the power of the instruction set available to a large mainframe is greater than that of a microcomputer of the same vintage. A large mainframe can have a variety of high level languages and applications software programs to suit the needs of its computing customers. The individual making use of a commercial time sharing system need not own a personal computer. All that is required for interaction with a time sharing system is a "dumb" CRT terminal or printer, a modem, and a telephone line. The typical cost of a modem and terminal is about $1,000, roughly comparable to the cost of the popular TRS 80 and Apple II personal computers.

The cost of computing, using a time shared mainframe, ranges from about $5.00 per hour (for MicroNET (tm) during off-peak hours) to about $20.00 per hour, with an average of about $10.00 per hour for the typical user. (This cost includes the cost of "connect time", and typical cost of the actual computation and of data storage, but not telephone costs). These costs have been relatively inflation-proof over the last decade so that, in fact, they are decreasing in constant dollar terms, as might be expected, given the characteristics of the underlying technology. Most of the larger time sharing service companies are connected to transational, or even international telecommunications networks, with local interface processors in major cities. Consequently, the typical user of time sharing service can gain access to almost global services with a local telephone call.

In cities where there is no message unit billing for private telephones, the added cost of telecommunications for personal computing by this method is negligible. For individuals in remote areas, or in circumstrances where message unit pricing is used, telecommunications costs can be a substantial portion of the cost of personal computing by trhis method. For example, the three minute message unit rate from Santa Monica to Central Los Angeles is 20 cents. A private personal computer/modem/telephone in Santa Monica connected to a time sharing computer with a Central Los Angeles telephone number would be paying an additional $4 per hour in telephone charges. Slightly farther out, in Malibu, the telephone rate is 19 cents a minute. Thus a Malibu resident wanting to engage in personal computing using the same system would incur $11.40 an hour in telephone charges, roughly doubling the cost of personal computing by this means.

Thus a person interested in personal computing via time sharing, and who might be expected to engage in personal computing for just two hours a week, could anticipate spending from about $600 to about $2,100 a year, depending on circumstances, with an average cost in a typical large metropolitan area of about $1,200 to about $1,500 per year.

Although most currently available computer time sharing services are oriented toward business and professional use, two personal computing oriented time sharing networks have come into existence since mid 1979. These are "The Source," from TCA, Inc., and MicroNET. In addition to the standard professional and business applications software mentioned previously, these systems also offer electronic message services, some data base access (for example, historical records of stock transactions), and transaction processing services of various sorts. Both systems currently make use of excess capacity available from computers which are primarily dedicated to business and professional time sharing services during normal working hours. Computer use charges are automatically billed to the customer's credit card. This excess capacity during off-peak hours has been made available to individuals interested in personal computing. The rates are correspondingly lower during these off-peak hours.

1.2 Teletext and Videotex Services

Teletext systems make use of the unused period between successive displays of a commercial television frame (the "blanking interval") to transmit textual information. The only equipment a user needs in the home is a decoder in, or attached to, the television set plus a relatively simple keyboard. Because Teletext can only be used within the frame blanking interval, it is limited in its capacity to about 400 "pages" of display. Each "page" consists of a character string, which when decoded, and displayed on the conventional TV set, will provide an alpha-numeric display similar to that presented by a personal computer which might use a home TV set as its display device (about 1,000 characters). The decoder, under the control of the Videotex user, "grabs" one of up to 400 text strings available within the blanking interval. Because Teletext is a broadcast, one way system, its uses are primarily data base oriented.

Videotex systems, on the other hand, while also using the home TV set as a display mechanism, employ a telephone line rather than a broadcast TV signal as the telecommunications medium. Consequently Videotex systems use bidirectional communications while Teletext systems are broadcast only. Because of their bidirectrionality, Videotex systems have considerably more latitude for expansion and technological improvement than Teletext. It is easy to envision a scenario in which a rudimentary home Videotex terminal is incrementally upgraded by its owner to the point where it becomes a full fledged telecommunicating personal computer.

There are, of course, hybrids between Videotex and Teletext systems in which the wideband TV signal is used in a Teletext-like mode on a CATV system, but where individual subscribers have the possibility of transmitting limited amounts of information back to the transmission station via a keyboard linked with the TV receiver. An example of this is the Warner Communications Qube System in Columbus, Ohio. The leader in development of Videotex has been the United Kingdom with its Prestel System.

Videotex systems, because of the greater sophistication of the home or office terminal, do cost more. Tyler notes (Tyler, 1978) that industry projections in the U. K. give an incremental cost to the purchase of a television receiver of from $400 to $550. This is consonant with the cost of a low end personal computer which has no user memory capacity. Teletext systems, on the other hand, would have terminal costs of about $100 to $200. These could be rented to the user for a monthly cost of from $3 to $6, while Videotex terminals would rent for about $12 to $15 per month (assuming the same amortization conventions as are used in commercial terminal rentals). Basic system use costs, according to Tyler, would be about $2.70 per month for Teletext systems and about $12.00 per month for Videotex systems.

Thus, the individual or business interested in personal computing would have some options available at costs lower than those involved in the purchase of a personal computer. However, many Videotex and all Teletext systems are currently limited to the provisions of data base services, although Videotex systems can engage in transaction processing and, in principle, other computer time sharing services.

1.3 Datacast

Another personal computer oriented network information service which has been undergoing acceptance testing for the last seveal months in the San Francisco area is called Datacast. The Datacast system uses one of the subcarriers of a commercial FM broadcast signal to broadcast text information. The system employs a simple decoder at the receiver, costing about $100.00. The system continually broadcasts news, advertisements, classified advertising, etc. This system requires a personal computer at the receiving site for effective use. The Datacast user has the option, depending on how his or her personal computer is programmed and the amount of storage available, of retaining all of the day's broadcasts or of simply flagging certain subject matter for subsequent display, according to the owner's wishes. Thus the Datacast subscriber could confine his or her information processing activities to articles on foreign affairs, advertisements for homes, local news, etc.

Since the Datacast system more closely resembles the traditional newspaper than any of the other network information services, there are a number of non trivial economic issues connected with its potential success. Foremost among these is the fact that the daily newspaper is generally supported largely by advertising rather than subscriber revenues. Given the present level of technology, generally limited to straight text transmission without extensive graphics, there may be severe difficulties in persuading the large number of advertising customers to participate in the program.

1.4 Acceptance of Network Information Services

There are a variety of sociological and psychological factors involved in the acceptance of network information services, and of personal computers, for that matter, in the office or in the home. Foremost among these is the ease with which one or the other of these potential manifestations of information technology can be integrated into our daily lives. Technologies which require a restructuring of normal living patterns for effective results are much less likely to be widely accepted than technologies which are more "comfortable."

> . . . when people are confronted with a choice between a fancy new technology they don't really understand and a dependable old technology (e.g., the telephone), they will typically choose the later - even if it is not the "°best' source". (Johansen, et. al, 1979).

More precisely, if the technology requires a great amount of initial effort before it is at all usable, then its acceptance is likely to be limited only to the few innovators who are going to put forth the effort for the necessary training.

As has been the case with personal computers over the past two years, it appears that the greatest initial acceptance of network information services will come from the business/government community. The primary reason for this is that both personal computer and network information service technologies are presently at the stage where facile access to the capabilities available requires a certain amount of training of the user. The typical potential home consumer of these services is not yet at the stage where he or she is motivated to undergo the necessary training. However, office workers who perceiv a need for the capabilities offered either by network information services or personal computers are motivated to accept the necessary training. As software technology progresses for both information technologies, and as training in interaction with computer services of various sorts becomes more widespread, then the gap between hardware/software capability and user training will diminish.

1.5 Forecast

Although network information services are viewed by some as complete alternatives to the use of personal computers, it appears that the two are complementary capabilities. Our experience has shown that those who begin their information processing experiences through network information services, as in the case of computer time sharing with dumb terminals, generally purchased personal computers for use in those activities which are of a relatively routine nature or which might otherwise require extended connection time to the network. Similarly, owners of stand-alone personal computers tend to become intrigued by the possibilities of inter computer communications for transaction processing and electronic messages systems and, particularly in business situations, for access to various databases. As the cost of personal computers goes down and relatively sophisticated software becomes more generally available for personal computers we would expect to see the greatest use of network information services concentrated in the functions dealing with ephemeral and/or perishable information such as transaction, electronic message, and database services, in that order of preference.

There are a number of policy issues concerning the future of network information services which are not covered by our research. In general, we would not expect that policy actions which tend to restrict the development of network information services will act to increase the use of personal computers to some extent. However, any such individual increase is likely to be less than the synergistic increase caused by the joint development of personal computers and network information services. The Institute for the Future is in the process of examining the policy aspects of Teletext and Videotex services with the support of a grant from the National Science

Foundation.

2. General Information Appliance (GIA)

In this form the PC, rather than being a separate, portable collection of boxes similar to a stereo system, is integrated into the home or office. The main information processing unit may be installed in a wall, as would an intercom system in a contemporary house. Connections to sensors and input/output devices would be made through internal house wiring or optical fibers, plugs and receptacles in appropriate places. Science fiction writers have anticipated this possibility (as well as the others to be discussed) years ago. The house or office would monitor its own physical condition, and that of its inhabitants, and perform the other information processing, entertainment, and educational functions described previously and in the literature. Whether the GIA becomes a reality in more than a scattering of homes in the United States by 1990 is dependent on many influences, such as technology, energy costs, concerns for security, manufacturer marketing decisions, etc. At this stage, we cannot expect a large number of such systems to be in existence prior to 1990.

3. Personal Information Utility (PIU)

This version of a personal computer goes the other direction: from distribution to concentration of the information utility. It is not a machine which, together with its sensors, is distributed throughout a house or office. Rather, it takes advantage of continuing microminiturization to allow packaging of the capabilities of contemporary PCs into an easily portable unit of at most a few cubic inches in volume. One description of an early possible version of a personal information utility is the Dynabook concept (Kay and Goldberg, 1977). The PIU would, in addition to being a sophisticated information processing capability, carry a substantial data base for use in the daily information transactions of its owner. Thus, the PIU would be a truly personal computer. Its appearance on the scene, if ever, is subject to the development of several technological factors as well as the resolution of a number of serious policy issues. A major one in this case is that of protection of personal privacy, since the PIU could be a collector and/or repository of a substantial amount of information which its owner would consider private, yet which might be retrievable by others if the unit were to be lost or stolen.

4. An Alternative Information Utility (AIU)

It is easy to visualize a merging and blurring of the PC concept, as we have discussed it thus far, with the network information services concept as embodied in the Viewdata system and the other network alternatives discussed earlier. In the pure network information service, as in the contemporary version of the Viewdata system, all of the information processing is done at a central facility. The user requests certain types of information, generally through a menu program method, and is charged for his access to the information on his telephone bill. Since the microelectronics industry is beginning to build specialized microprocessors for Viewdata-type terminals which will be easily expandable to form stand alone microcomputers, it is clear that some hybrid version of these two approaches to information systems could develop. If potential conflict between the personal computer industry and the network information services providers cannot be resolved by market processes or if the market process resolution of the conflicts is perceived to be contrary to the best interest of the citizenry, then the areas of conflict give rise to public policy issues.

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APPENDIX I

UNIVERSITY OF SOUTHERN CALIFORNIA
OFFICE OF INTERDISCIPLINARY PROGRAMS
LOS ANGELES, CA 90007

PERSONAL COMPUTER USER'S QUESTIONNAIRE NO. 2

November, 1978

The University of Southern California is conducting a study of the Personal Computer. Part of this study involves finding out what sort of people buy Personal Computers, what sort of devices they buy and what they use them for.

As an existing or potential Personal Computer owner and user, your help in answering this Questionnaire is much appreciated and will provide the study team with very valuable information. If you have any questions about this study, you may phone Celeste Akkad at (213) 741-7464. Your answers will be used for research only.

A. EQUIPMENT

Please indicate below the Personal Computer equipment you have acquired, may have sold or stopped using, and expect to acquire.

Principal Computer

	mo/yr Acquired	Stopped Using	Expect to Get
Altair 8800	__/__	__/__	__/__
Apple II	__/__	__/__	__/__
Commodore PET	__/__	__/__	__/__
Compucolor II	__/__	__/__	__/__
Cromemco	__/__	__/__	__/__
Heathkit H8	__/__	__/__	__/__
Heathkit (DEC)H11	__/__	__/__	__/__
IMSAI 8080	__/__	__/__	__/__
SOL	__/__	__/__	__/__
TRS-80	__/__	__/__	__/__
VideoBrain	__/__	__/__	__/__
Other ____________________	__/__	__/__	__/__
____________________	__/__	__/__	__/__

Peripherals or Characteristics	Acquired mo/yr	Cost	Expect to get	Cost
AC Line Control for appliances	__/__	_____	__/__	_____
Analog/Digital Converter	__/__	_____	__/__	_____
Cassette Tape I/O	__/__	_____	__/__	_____
Cathode Ray Tube	__/__	_____	__/__	_____
Color Graphics	__/__	_____	__/__	_____
Floppy Disk (5 1/4")	__/__	_____	__/__	_____
Floppy Disk (8")	__/__	_____	__/__	_____
Hardcopy Printer	__/__	_____	__/__	_____
Joy Stick or Paddle	__/__	_____	__/__	_____
MagCard Reader	__/__	_____	__/__	_____
Modem	__/__	_____	__/__	_____
Parallel Communications Interface	__/__	_____	__/__	_____
Record & Playback	__/__	_____	__/__	_____
ROM Board	__/__	_____	__/__	_____
Serial Communications Interface	__/__	_____	__/__	_____
Speech Recognition	__/__	_____	__/__	_____
TV Link to Computer	__/__	_____	__/__	_____
Wand or Pointer	__/__	_____	__/__	_____
Other _______________	__/__	_____	__/__	_____
_______________	__/__	_____	__/__	_____
_______________	__/__	_____	__/__	_____

CPU Memory Size of your present and expected personal computer

	0-1	2-4	5-8	9-16	17-24	25-32	33-48	48-65	66+
Now Have	___	___	___	___	___	___	___	___	___
Expect w/in 1 yr	___	___	___	___	___	___	___	___	___

B. APPLICATIONS

Please indicate below what applications you have made.

Standalone uses for Personal Computer

	Date Acquired	Expected Acquisition Date	Cost
Videogames (Star Wars, etc.)	__/__	__/__	____
Board Games (Chess, Black Jack)	__/__	__/__	____
Letter & Reports Preparation	__/__	__/__	____
Text Editing	__/__	__/__	____
Household appliance Control	__/__	__/__	____
Address Lists & Sorts	__/__	__/__	____
File Maintenance and Search	__/__	__/__	____
Inventory, Reorder, etc.	__/__	__/__	____
Sales Record and Analysis	__/__	__/__	____
Checkbook Records and Balancing	__/__	__/__	____
Budgeting, Personal or Business	__/__	__/__	____
General Ledger	__/__	__/__	____
Amortization Computation	__/__	__/__	____
Stock/Bond Analysis	__/__	__/__	____
Income Tax Preparation	__/__	__/__	____
Recipe Storage and Calculation	__/__	__/__	____
Speech Recognition	__/__	__/__	____
Speech Generation	__/__	__/__	____
Music Generation or Playing	__/__	__/__	____
Graphics Production or Display	__/__	__/__	____
Simulation	__/__	__/__	____
Teaching Machine	__/__	__/__	____
Test Administration or Scoring	__/__	__/__	____
Other ________________	__/__	__/__	____

Do you use your personal computer to access other computers in a network?

____Yes ____No

If yes, please check the applications you use :

____Banking services

____Purchasing

____Directory of goods & services

____Catalog shopping

____Electronic messages

____Automatic fire &/or burglar alarm, or other emergency services

____Educational services

____Entertainment on demand

____Data base access

____Games

____Viewdata-like service that combines a number of the above

C. COMPUTER LANGUAGES YOU USE OR HAVE USED

	At School	At Work	Personal Computer
APL	____	____	____
Assembly	____	____	____
BASIC	____	____	____
COBOL	____	____	____
FORTRAN	____	____	____
Other ____________	____	____	____
____________	____	____	____
____________	____	____	____

D. COST

1. How much have you spent, approximately, on your personal computer?

Original Investment	Subsequent Investment
____under $1,000	____under $1,000
____$1,000 to $1,999	____$1,000 to $1,999
____$2,000 to $4,999	____$2,000 to $4,999
____$5,000 to $9,999	____$5,000 to $9,999
____$10,000 & over	____$10,000 & over

2. What percent of the cost of your equipment was paid for by someone other than yourself? (business, school,etc.)

0 1-20 21-40 41-60 61-80 81-100

source of funds:

employer	____
school	____
personal gift	____
other	____

3. Have you been able to deduct your Personal Computer from your income tax as a business expense?

___all ___some

___none

E. INFORMATION SOURCES

1. How do you rate your sources of information about Personal Computers? ((5=excellent source; 4= good source; 3=satisfactory source; 2=poor; 1=awful; 0=no contact,don't know)

____articles in publications
____advertisements in publications
____technical books
____manufacturers' literature
____school courses
____computer clubs
____trade shows/conferences
____job
____computer stores
____informal personal contacts with users
____ other

2. Please check those computer magazines which you regularly read:

____BYTE
____COMPUTER HOBBYIST
____COMPUTER MUSIC JOURNAL
____CREATIVE COMPUTING
____DATAMATION
____DR.DOBBS JOURNAL
____INTERFACE
____INTERFACE AGE
____KILOBAUD
____MINI-MICRO SYSTEMS
____ON-LINE
____PEOPLES COMPUTING CO.
____PERSONAL COMPUTING
____ROM

3.Please check those computer-related organizations or associations of which you are a member:

____ACM
____AFIPS
____ASIS
____AEDS
____IEEE-CS
____ISA
____SIAM
____SLA
____Professional and Technical
____Consultants Association
____Personal Computer club

____ACL
____AICPA
____ASA
____DPMA
____IIA
____SCS
____SID
____California Math Council
____TIMS
____ORSA
____Other

F. PERSONAL INFORMATION (OPTIONAL)

1. Age:

____under 20
____20-29
____30-44
____45-60
____over 60

2. Sex:

____F
____M

3. Ethnic Background:

____Black
____Caucasian
____Native American
____Oriental
____Spanish Surname
____Other

4. Annual Income:

____under $10,000
____$10,000-$19,000
____$20,000-$29,000
____$30,000-$50,000
____over $50,000

5.Education:

____Currently attending High School
____Did not complete High School
____High School Diploma
____Some college courses
____A.A. Degree
____Bachelor's Degree
____Masters
____Doctor

6.Major Field:

____Liberal Arts
____Business
____Engineering
____Health Science
____Other

____Natural Science/Math
____Social Science
____Law
____Computer Science

7. Where did you receive your knowledge of computers? Comments.

____graduate school ____________________

____undergraduate school ____________________

____high school ____________________

____elementary school ____________________

____military ____________________

____on-the-job ____________________

____self-taught ____________________

____other ____________________

8a. Occupation:

____Clerical/Sales

____Consultant

____Educator

____Electrical Engineer

____Engineer (non-Electrical)

____Fine/Performing Arts

____Government/Military

____Legal

____Management

____Medical

____Programmer/Analyst

____Student

____Technician

____Other

b. Size of company (approximate number of employees):____________

c. Occupations since graduation:____________________

____

____

9a. Do you yourself use computers on your job? ____No ____Yes

b. Do your subordinates or coworkers use them? ____No ____Yes

c. Do you use computer outputs on the job? ____No ____Yes

10. Which of the following electronic devices have you or your family owned? Please specify year of purchase.

____ video games
____ video recorder
____ programmable calculator
____ calculator (other)
____ number of radios
____ stereo system
____ ham radio
____CB radio
____Number of TV's

11. What are some of your hobbies or interests?____________________

____

____

G. EVALUATION OF PERSONAL COMPUTING

1. The BEST thing about personal computing is ________________

____

____

2. The WORST thing about personal computing is ________________

____

____

3. The MOST IMPORTANT thing about personal computing is ______

____

____